From: Institute of City Planning and Urban Design
Faculty of Engineering, Department of Civil Engineering

Low-Carbon Indicator System – Sino: Evaluating Low-Carbon City Development Level in China

Thesis
Submitted for the fulfillment of the degree of
Doctor of Engineering (Dr. -Ing.)
in Faculty of Engineering
in University of Duisburg-Essen

Essen, 2016

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Datum der Einreichung: 28. January 2016
Datum der Verteidigung: 20. April 2016

Abstract

Climate change is affecting human society in different aspects, thus attracting global focus. With over half of the global population now living in urban areas, cities will face great challenges as they are hotspots for disaster and climate risks and major contributors to greenhouse gas (GHG) emissions. However, as a highly artificial system, urban development depends on human decisions to a large extent. It is possible to minimize the influence through reasonable development strategies. The previous concept and endeavor of sustainable cities likely need to be adjusted according to climate change. China and other emerging countries are experiencing a rapid urbanization, industrialization and modernization process that will result in a significant increase in economic development and urban construction in the future decades. In this process, if the urban development follows the traditional pattern, once they are built, cities will be locked in an energy- and carbon-intensive development model over a considerable period of time. Low-carbon city development will ensure that the process is more resilient to potential climate crisis and at the same time prevent aggravation of the ongoing climate change. Therefore, there is an urgent need to develop an appropriate evaluation framework of low-carbon city development levels in China.

German Federal Ministry of Education and Research (BMBF) launched the "Cooperative Project Shanghai: Integrated Approaches towards a Sustainable and Energy-Efficient Urban Development – Urban Form, Mobility, Housing and Living" in 2008 and entrusted the Institute of City Planning and Urban Design at the University of Duisburg-Essen to develop a tool "Low Carbon Index (LCI®)" to evaluate the energy-efficiency and CO_2 emissions of urban areas, which has been tested in the Shanghai Hongqiao Low Carbon Business Center project. This evaluation tool is intuitive and understandable, and provides a new consideration for the study of low-carbon city evaluation, but improvements are still needed in terms of practice guidance, operability, flexibility, etc. Under this background, the aim of the thesis is to develop a low-carbon city evaluation system for Chinese cities based on the experience of LCI®, in order to provide standards and guidance for low-carbon city development in China.

Firstly, the connotation and definition of the low-carbon city was taken from a review of the theory and its background. Based on the review of existing research achievements, the low-carbon city is defined as a city that strives to reduce its GHG emissions and increase its carbon sinks, while simultaneously adapting to the anticipated climate change impacts. This definition suggests that climate mitigation and adaptation are two key points of low-carbon city development with the same significance, and identifies these both as the main basis of low-carbon city evaluation.

Secondly, six key climate-related urban sectors of “urban design”, “transport”, “energy”, “building”, “water”, and “municipal solid waste” were identified and their significance in low-carbon city evaluation, carbon emission contribution, climate risk, and climate mitigation and adaptation strategies were studied in depth. Action in these six sectors could substantially improve the level of low-carbon development in a city, thus, it indicates the orientation of low-carbon city evaluation.

Thirdly, an evaluation framework of low-carbon city development level – Low-Carbon Indicator System – Sino (LCISS) is constructed. It consists of three parts: “indicator list”, “evaluation checklist and report”, and “development guideline”. “Indicator list” is the evaluation tool, which is a comprehensive indicator system constructed through coupling three urban planning scales with the six key urban sectors. It is organized as a three-level hierarchic structure that contains 6 first-class indicators, 17 second-class indicators, and 54 third-class indicators. All indicators of this system are selected by using Theoretical Analysis method and Delphi method, and the weight of the indicators is determined by Delphi method and Analytic Hierarchy Process (AHP) method. “Evaluation checklist and report” is the evaluation result as well as a systematic review of the situation of a city’s low-carbon development level. “Development guideline” is an action plan that describes where improvement is needed in the future. The feature of LCISS is that it could help cities to evaluate the process and status of their low-carbon development, to identify where inefficiencies occur as well as where action is needed, to assess the potential for improvement, and to formulate an action plan, so as to advance the low-carbon development in a more efficient way.

Finally, the evaluation framework of Low-Carbon Indicator System – Sino was tested using the Sino-Singapore Tianjin Eco-City (SSTEC) project as an example. The evaluation results showed that SSTEC has advantages in low-carbon development at all three urban planning scales, but there is still room for improvement in several sectors, such as traffic management, building certification, flood control, and waste recycling regulations. The results of this evaluation conform with the actual development situation of SSTEC.

It is expected that this thesis will be of practical value for the low-carbon city evaluation process.

Zusammenfassung

Der Klimawandel gewinnt zunehmend weltweite Aufmerksamkeit; denn er beeinflusst die Gesellschaft in vielfältiger Weise. Über die Hälfte der Weltbevölkerung lebt heute in Großstädten. Daher werden diese großen Herausforderungen zu bewältigen haben; denn sie werden sowohl Brennpunkte für Klimakatastrophen und –risiken als auch die Hauptverursacher der Treibhausgasemissionen sein. Stadtentwicklung ist ein hochkomplexes künstliches System, das hauptsächlich von menschlichen Entscheidungen abhängig ist. Insofern können vernünftige Entwicklungsstrategien Katastrophen und Risiken minimiert werden. Bisherige Konzepte und Bemühungen zukunftsfähiger Städte müssen dem Klimawandel entsprechend angepasst werden. China und andere Schwellenländer erleben gerade einen rapiden Urbanisierungs-, Industrialisierungs- und Modernisierungsprozess, der in einem bedeutenden Anstieg von Bauprojekten und wirtschaftlicher Entwicklung in den kommenden Jahrzehnten münden wird. Wenn die Stadtentwicklung dem bisherigen Muster folgt, werden die Städte, sobald sie gebaut sind, über einen beträchtlichen Zeitraum in einem energie- und kohleabhängigen Entwicklungsmodell stecken bleiben.

Umweltfreundliche Stadtentwicklung garantiert eine belastbarere Entwicklung im Angesicht einer potentiellen Klimakrise und beugt gleichzeitig einer Verschärfung des andauernden Klimawandels vor. Daher ist es dringend notwendig, angemessene Bewertungsmaßstäbe für umweltfreundliche Entwicklungsstufen in China zu entwickeln.

Das deutsche Bundesministerium für Bildung und Forschung (BMBF) startete 2008 das „Cooperative Project Shanghai: Integrated Approaches towards a Sustainable and Energy-Efficient Urban Development – Urban Form, Mobility, Housing and Living” und beauftragte das Institut für Stadtplanung und Städtebau an der Universität Duisburg-Essen mit der Entwicklung des „Low Carbon Index (LCI®)”, um Energieeffizienz und CO2 Emissionen im städtischen Raum bewerten zu können. Dieser Index wurde bereits im Shanghai Hongqiao Low Carbon Business Center Projekt getestet. Dieses Bewertungsinstrument ist intuitiv und verständlich und stellt eine neue Betrachtungsweise für die Erforschung der Bewertung umweltfreundlicher Städte dar, allerdings sind immer noch Verbesserungen vonnöten, was den Praxisbezug, die Bedienbarkeit und die Flexibilität anlangt. Vor diesem Hintergrund ist das Ziel der Arbeit, ein System für die Bewertung der Umweltfreundlichkeit chinesischer Städte auf der Praxiserfahrung des LCI® zu entwickeln, um Standards und Anleitungen für eine umweltfreundliche Stadtentwicklung in China zur Verfügung stellen zu können.

Zunächst wurden Inhalte und Definition einer umweltfreundlichen Stadt hergeleitet aus der Betrachtung der Theorie und deren Hintergrund. Basierend auf der Auswertung bereits vorhandener Forschungsergebnisse ist die umweltfreundliche Stadt als eine definiert, die sich für eine Reduzierung der Treibhausgas-Emissionen und Anhebung

der Kohlenstoffsenken einsetzt, während sie sich gleichzeitig an die erwarteten Auswirkungen des Klimawandels anpasst. Diese Definition unterstellt, dass Klimaschutz und -anpassung zwei elementare Schlüsselaspekte der umweltfreundlichen Stadtentwicklung von gleichrangiger Bedeutung sind, und bestimmt diese beiden auch als Hauptgrundlage für die Bewertung der umweltfreundlichen Stadt.

Zweitens wurden die sechs stadtrelevanten Klimafaktoren Stadtgestaltung, Transport, Energie, Gebäude, Wasser und kommunale Abfälle bestimmt und ihre Bedeutung für die Bewertung der umweltfreundlichen Stadt, den Anteil an Kohlenstoffemissionen, die Klimagefährdung, den Klimaschutz und Anpassungsstrategien ausgiebig untersucht. Ein Handeln in diesen sechs Bereichen könnte erheblich den Grad einer umweltfreundlichen städtischen Entwicklung steigern. Damit werden auch die Richtlinien für eine Bewertung umweltfreundlicher Städte bestimmt.

Drittens wird ein Bewertungsrahmen zur Bemessung der umweltfreundlichen Stadtentwicklung – Low-Carbon Indicator System – Sino (LCISS) geschaffen. Er besteht aus drei Teilen: „indicator list”, „evaluation checklist and report”, und „development guideline”. Die Indikatorenliste ist ein Bewertungsinstrument, welches ein komplexes Indikatorensystem darstellt, das sich zusammensetzt aus der Verbindung von drei urbanen Planungsmaßstäben mit den o.g. sechs Faktoren. Konstruiert ist sie in einem dreistufigen hierarchischen Aufbau, der sechs erstrangige, 17 zweitrangige und 54 drittrangige Indikatoren enthält. Alle Indikatoren dieses Systems werden gewählt, indem die Theoretische Analyse Methode und die Delphi Methode zum Tragen kommen. Die Gewichtung der Indikatoren wird durch die Delphi Methode und die Analytische Hierarchie Prozess (AHP) Methode festgelegt. Bewertung, Checkliste und Bericht („evaluation checklist and report”) meint das Bewertungsergebnis ebenso wie die systematische Erfassung des Entwicklungsstands der gegenwärtigen städtischen Umweltfreundlichkeit. Entwicklungsrichtlinie („development guideline”) bezieht sich auf den Aktionsplan, der beschreibt, wo Verbesserungen nötig sind. Das Leistungsmerkmal des LCISS ist, Städten zeigen zu können, wie man den Prozess und gegenwärtigen Stand einer umweltfreundlichen Entwicklung bewerten, Ineffizienzen herausfinden und Aktionsbedarf, Verbesserungsmöglichkeiten und Aktionspläne ermitteln kann, um die umweltfreundliche Entwicklung effektiver zu gestalten.

Schließlich wurde der Bewertungsrahmen des Low-Carbon Indicator Systems – Sino getestet, indem das Sino-Singapore Tianjin Eco-City (SSTEC) Projekt als Beispiel herangezogen wurde. Die Bewertungsergebnisse zeigten, dass das SSTEC zwar Vorteile in der umweltfreundlichen Entwicklung auf allen drei städtischen Planungsebenen bringt, jedoch immer noch Raum für Verbesserungen in einigen Bereichen da ist, beispielsweise in der Verkehrsplanung, der Gebäudebewertung, dem Hochwasserschutz und den Abfallaufbereitungsverordnungen. Die Ergebnisse dieser Bewertung stimmen mit der aktuellen Entwicklungssituation beim SSTEC überein.

Es wird erwartet, dass diese Arbeit von praktischem Nutzen für einen umweltfreundlichen Stadtentwicklungsprozess ist.

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Acknowledgments

I would like to thank the financial support of my doctoral work from German Academic Exchange Service (DAAD) and Chinese Scholarship Council (CSC), and great support from the programme of Advanced Research in Urban System (ARUS).

I would like to express my grateful thanks to the following people. This thesis would not have been possible without the support of any of them.

I own my deepest gratitude to my supervisor, Prof. Dr. J. Alexander Schmidt, for giving me the chance to study in Germany, for his guidance with enthusiasm, patience and profound knowledge, and for his consideration and encouragement during my study; to Dr. Jiang Liu for his friendly support and professional feedback on my dissertation; and to Prof. Dr. Guangwen Meng, for encouraging me to study in Germany and sharing his valuable professional experiences.

I express my gratitude to all the participants who were involved in my study: Shaojun Yuan, Tianxin Hu, Zhongxiu Zhang and Guangqi Liu at China Academy of Urban Planning & Design, Xiaofeng Sun at Construction Bureau Sino-Singapore Tianjin Eco-City, Yicheng Gao at China Architecture Design & Research Group, Zhenqiang Xu at Chinese Society for Urban Studies, Suzhen Ma at China Academy of Building Research Shanghai Institute, Lu Zhao at Shanghai Urban Planning and Design Research Institute, Iris Belle at Future Cities Lab (Singapore), Wei Qiao at Shanghai Hongqiao Central Business District Administrative Committee, Hui Xie, Peifeng Yang and Haoyan Wei at Chongqing University, Chaolin Gu at Tsinghua University, Wenli Dong at Zhejiang University, Jin Zuo and Li Zhu at Tianjin University, Lijie Gao at Institute of Urban Environment of Chinese Academy of Sciences. Their contributions built the strongest basis of my thesis.

I am thankful to all my colleagues at Institute of City Planning and Urban Design (ISS) and ARUS for their friendship and support, and for creating a great working atmosphere.

Finally, my sincere gratitude goes to my family for their continuous love and support. I would like to thank my husband Kevin for his understanding and love during the past four years. His support and encouragement was in the end what made this dissertation possible. I am indebted to my parents. Without their many years of dedication and support, I could not come so far in my education.

Chapter 1 Introduction

1.1 Research background

Climate change has been an unequivocal fact, as is now evident from climatological models and observations at different levels and from the work of the Intergovernmental Panel on Climate Change (IPCC), according to which the global average temperature has increased by 0.74ºC from 1906 to 2005 (Pachauri and Reisinger 2007). Human activities, such as the use of fossil fuels, changes in land use, agriculture, etc., have played crucial roles in this process (Figure 1.1). In 2013, the 5th assessment report of the IPCC stated that human influence on the climate system is clear (Stocker, Qin et al. 2014). An explicit example of this is that the atmospheric concentration of CO_2 has increased from a pre-industrial level of about 280ppm to 379ppm in 2005 (Solomon, Qin et al. 2007). Without efficient climate mitigation efforts, the global average temperature is expected to rise by 1.1-6.4ºC relative to 1980-1990 by the end of this century, depending on different scenario assumptions (Pachauri and Reisinger 2007).

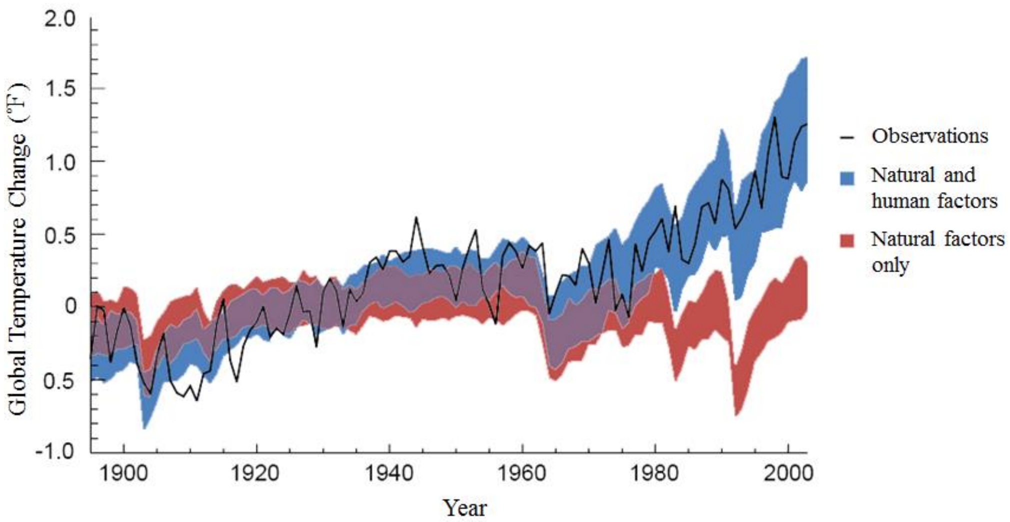

Figure 1.1 Separating human and natural influences on climate
Source: (Melillo, Richmond et al. 2014)

The consequences of climate change include far more than temperature change and may also include melting ice, rising sea levels, changes in precipitation patterns, more frequent and severe extreme weather events (incl. heat waves, cold spells, extreme precipitation events, and storms), etc. Global warming causes glaciers, ice caps and polar ice sheets to melt. As the IPCC projected, over one-sixth of the world's population relying on meltwater will be affected by water supply reduction and drought problems (Parry, Canziani et al. 2007). A combination of the change "melting ice" is sea level rise. According to recent calculations, sea levels will increase by 0.8-2m by 2100 (Pfeffer, Harper et al. 2008). This poses a threat for low-elevation coastal zones

(LECZ)[1] that are at risk of eventually being submerged underwater. Additionally, rising sea levels will increase the risks of inundation and destructive storm surges in LECZs. The precipitation pattern is also prone to severe changes that are likely to lead to increased floods and/or droughts in some regions. Moreover, extreme weather events are expected to occur more frequently and be more intensive. All the changes could significantly impact a range of environmental, economic and social processes that are affected by the weather.

It is expected that climate will continue to change over the coming decades as there is a time lag in the climate system (Parry, Canziani et al. 2007). Whereas, if effective mitigation[2] action is taken now, there is still a chance to limit the carbon dioxide levels less than 560ppm, the threshold carbon dioxide concentration for dangerous consequences predicted by the IPCC. On the other hand, considering the levels of carbon dioxide that have been emitted in the past and its lifetime in the atmosphere, adaptation[3] of some level of climate change is likely to be an inevitable choice. For integrating both mitigation and adaptation as responses to climate change, an urgent shift toward to low-carbon development is required. Furthermore, as the major global sources of greenhouse gas (GHG)[4] emissions, and disaster and climate risk hotspots, cities are playing an increasingly active role in the climate change response, particularly in six key urban sectors: urban design, transport, energy, building, water, and municipal solid waste. Therefore, the concept of low-carbon city development will be introduced and discussed in this work, as well as establishing a low-carbon city evaluation system for China, the biggest carbon emitter worldwide, on the basis of studying how these key urban sectors influence the construction of low-carbon cities.

1.2 Cities and climate change

1.2.1 Contribution of cities to climate change

Cities are key sources of CO_2 emissions, as they are centers of human activities of production and consumption that greatly contribute to carbon emissions such as transportation, industrial production etc.

Currently, due to the lack of a globally accepted calculation method, carbon emissions from cities cannot be pinpointed. However, cities' characteristic of energy- and carbon-intensive has been widely documented. Estimates suggested that as much as 80% of the world's carbon emissions were sourced from cities and their residents (Churkina

[1] Low-elevation coastal zone (LECZ) refers areas adjacent to the coast that less than 10 meters above mean sea level.
[2] According to IPCC, mitigation is defined as anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases.
[3] According to IPCC, adaptation is defined as adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.
[4] According to the Kyoto Protocol, greenhouse gases include: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). Among them, CO_2 is the major element, accounting 72% of the totally emitted greenhouse gases.

2008, Hoornweg, Bhada et al. 2010, Xue, Han et al. 2010). According to a report of United Nations Human Settlements Programme (UN-HABITAT), the main sources of global GHG emissions include energy generation, transportation, building construction and operation, industrial production, waste treatment and disposal, and agriculture and forestry (UN-Habitat 2011). As shown in Figure 1.2, most sources are associated with cities and their functions.

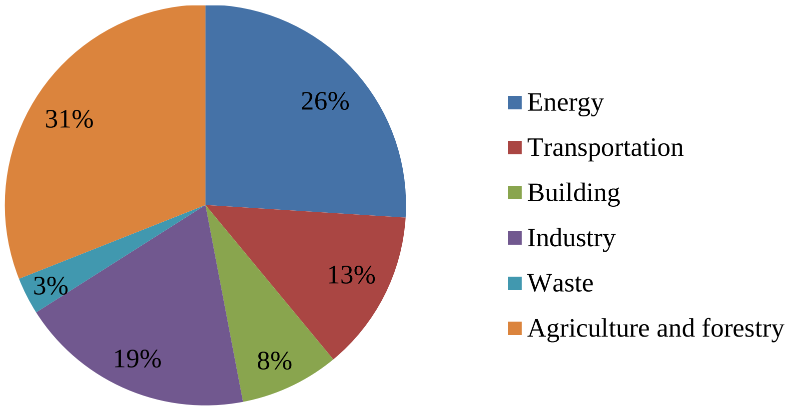

Figure 1.2 The sources of GHG emissions
Source: Author based on (UN-Habitat 2011)

A recent study of 114 countries around the world suggests that economic growth and population were important driving factors behind increasing global CO_2 emissions in the last decades (Pani and Mukhopadhyay 2010), and cities are the most important carriers of population and economy. By now, cities are home to more than half of the world's population. In 1950, only 30% of the world's population (746 million) lived in cities; in 2014, this number rose up to 54% – 3.9 billion people were urban residents (United Nations 2014). Figure 1.3 clearly illustrates that global CO_2 emissions have been rapidly growing with urban population growth in the last half-century. As projected by U.N., 66% of the global population will be living in cities by 2050, which will further drive carbon emission growth. Moreover, cities provide opportunities, benefits and generate more than 80% of global Gross Domestic Product (GDP) (The World Bank 2015). The relationship between global CO_2 emissions and economic growth is shown in Figure 1.4 that GDP per capita is positively related to carbon emissions. However, at different stages of the development of a city, this relationship can take different forms (He and Richard 2009), (Martínez-Zarzoso and Bengochea-Morancho 2004, Galeotti, Lanza et al. 2006).

The above analysis suggests that cities are significant contributors to CO_2 emissions, thus, they should be stakeholders in all climate mitigation efforts. Due to the concentration of considerable economic resources, skilled people, creative industries, cities play irreplaceable roles in addressing the climate change issues.

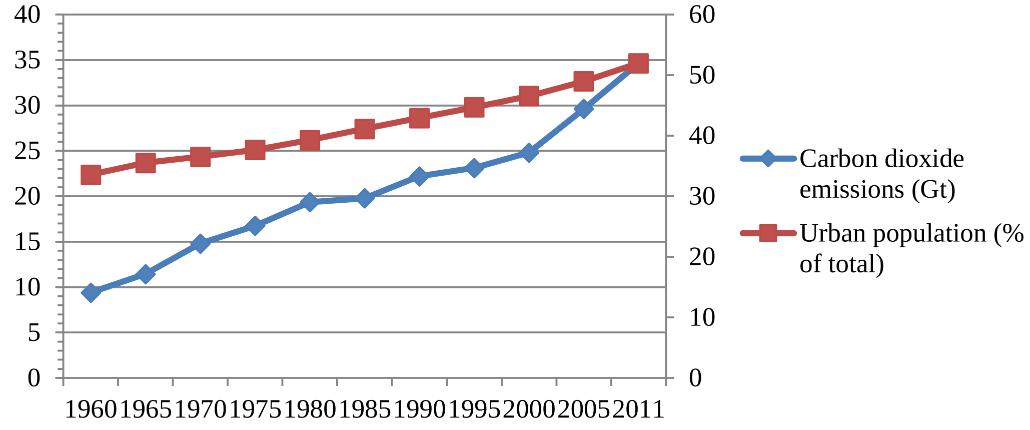

Figure 1.3 Comparison of global CO_2 emissions and urbanization development
Source: Author based on the World Bank Data

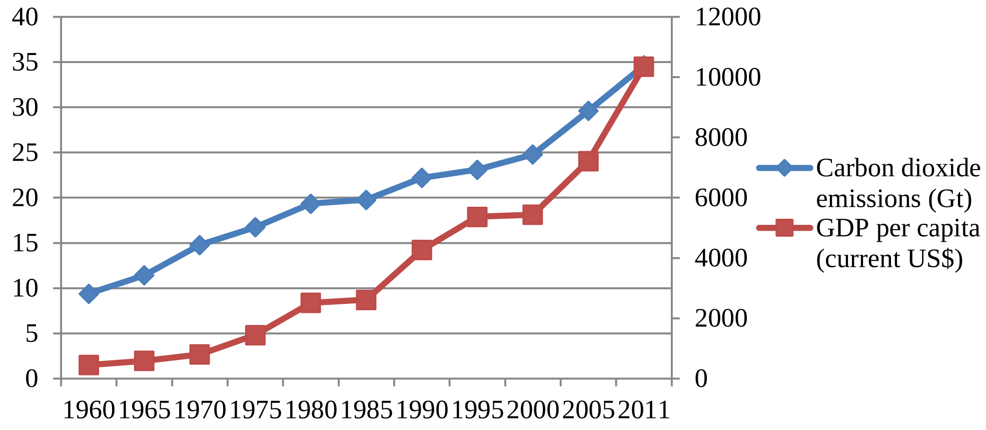

Figure 1.4 Comparison of global CO_2 emissions and economic growth
Source: Author based on the World Bank Data

1.2.2 Impacts of climate change on cities

Cities account for approximately 80% of global CO_2 emissions. They also face the worst risks from the ultimate consequences of those emissions, as most of the world's cities are clustered on costal lands, especially the low-elevation coastal zones. Although the LECZs take up only 2% of the world's area (McGranahan, Balk et al. 2007), but they contain 10% of the world's population and 60% of the urban population (Dickson, Baker et al. 2012). In light of the UN-Habitat's analysis of the relationship between cities and current climate-related hazards, most cities are situated in high hazard risk areas (Figure 1.5). In addition, cities with more people, resources, industry, and infrastructure will be more adversely affected by climate change in the future. At present, more than half of the world's population and much of the world's industry are concentrated in urban areas, and surely, as urbanization grows, this trend will continue and further aggravate in the future. It may lead to increased exposure to climate change hazards.

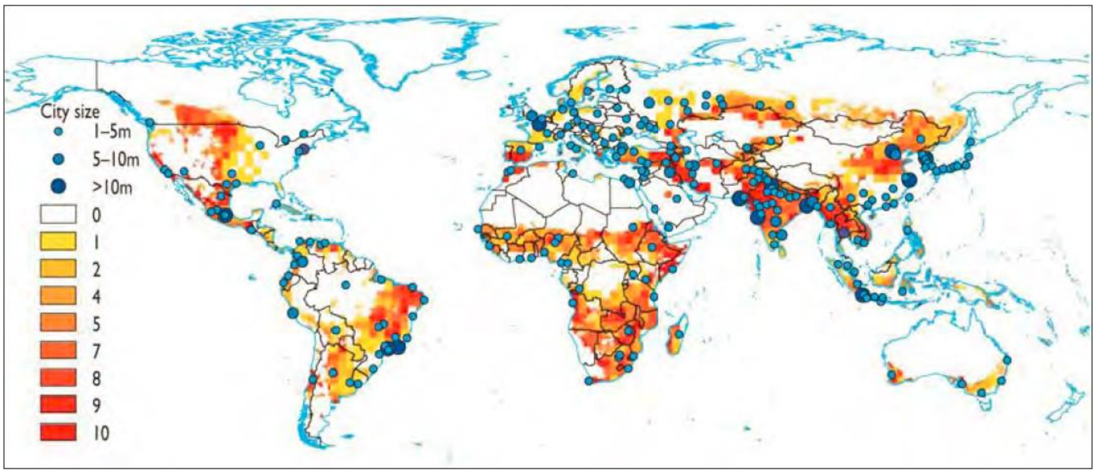

Figure 1.5 Cities in relation to current climate-related hazards
Note: The urban areas included in this figure have populations greater than 1 million. The hazard risk represents a cumulative score based on risk of cyclones, flooding, landslides and drought. A score of '0' denotes 'low risk' and '10' denotes 'high risk'.
Source: (UN-Habitat 2011)

As discussed, climate change is supposed to result in warmer temperatures, rising sea levels, changed precipitation patterns, more frequent and intensive cyclones and storms, extreme precipitation events, more extreme heat waves and cold spells. These physical changes and their associated eco-systemic and economic responses have discernible impacts on cities worldwide (Table 1.1).

Table 1.1 Sample of climate hazards and impacts on cities

Projected change in climate phenomena (likelihood)	**Drivers of urban exposure and vulnerability**	**Consequences for cities, if unaddressed**	**Sectors involved**
Warmer with fewer cold days and nights, more hot days and nights (virtually certain) Hot spells/heat waves —increased frequency (very likely)	Urban heat island effect. Lack of electricity and cooling systems, especially in many informal settlements.	Exacerbated air pollution Heat-induced illness and death	Transportation, housing, private sector building industry, public health
	Lack of diversified energy supply and substandard energy infrastructure.	Energy shocks and disruptions because of increased demand	Energy
Heavy precipitation events—increased frequency (very	Rapid urban growth leading to informal settlements on	Exacerbated flooding and landslides	Land use, housing, solid waste, public health, emergency

likely) Intensity of tropical cyclone activity increases (likely)	marginal land with no roads or drainage systems, or drains that are clogged with debris and silt.	Contaminated waters and spread of disease in stagnant waters	management
Rising sea level (virtually certain)	Nonexistent or substandard transportation infrastructure.	Blockage of emergency routes because of road flooding, resulting in delayed emergency evacuations Losses in commercial activity	Transportation, emergency management, private sector
	Storm water infrastructure unable to deal with current or future runoff, compounded by deforestation / degradation of natural storm water filtering functions.	Increased runoff in absence of vegetated land Increased flooding	Sanitation, solid waste Natural resources management
	Already high population densities and concentrated commercial activities (for example, ports and industry), located in coastal cities or in river deltas.	Loss of property and infrastructure, potentially before the end of their useful life	Private sector
	Lower structural quality of homes, especially in informal settlements.	Loss of property and life	Housing, emergency management
	Location of aquifers, wastewater	Saltwater infiltration of infrastructure (for	Water supply Wastewater

	treatment plants, and other infrastructure in coastal areas or on river deltas.	example, potable water supplies and wastewater treatment)	treatment
Areas affected by drought increase (likely)	Existing water scarcity and competing pressures for water use (for example, potable water, irrigation, wastewater, or hydropower).	Exacerbated water scarcity and competition	Water supply (with implications for energy sector in areas of hydropower generation)
		Food shortages or higher food prices because of impacts in other parts of the region or world.	Food and agriculture

Source: (The World Bank 2011)

Facing the impacts above, cities in developing countries are often more vulnerable compared to cities in developed countries. On one hand, as the population in developing countries is large, cities in these regions are particularly densely populated. Additionally, many developing countries are experiencing the process of rapid urbanization, and it is expected that most of the world's urban population growth will occur in these countries during the next decades (Heilig 2012). This can significantly increase climatic threats and exacerbate global warming. On the other hand, lacking economic strength, cities in developing countries are less able to make significant investments to upgrade their infrastructure to better withstand natural hazards, such as storm surges and flooding.

Given the above analysis, cities are important factors in tackling disasters and climate change. To realize sustainable development, action should be taken to make cities more resilient to anticipated climate change impacts.

1.3 Climate change in China

Since 2006, China has been the top emitter of carbon dioxide in the world, accounting for 29% of the total global CO_2 emissions and its increase was equivalent to about 60% of the world's net CO_2 increase in 2013 (Olivier, Janssens-Maenhout et al. 2014). Chinese cities, representing 54% of the total population and 78% of total GDP (Manyika, Remes et al. 2012), contribute 85% of China's carbon emissions (Dhakal 2009). A recent research found that the total carbon emissions from 150 Chinese cities are around 6006Mt carbon equivalence in 2010, which contributes 70% of total carbon emissions in China (Liu 2015).

With the constant development of the economy in China, urban population continues to grow steadily. As estimated by McKinsey, there will be another 350 million people living in Chinese cities by 2025, and more than 240 million of them will be migrants (Woetzel, Mendonca et al. 2009). An inevitable consequence of this process is that energy consumption and corresponding CO_2 emissions will be accelerated since urban citizens' energy consumption is about 3.5 times that of rural residents (Liu and Deng 2011).

From another point of view, China itself is also one of the most vulnerable countries to climate change. The existing research indicated that the general tendency of climate change in China accords with global climate change. According to the Third National Assessment Report on Climate Change, during 1909 to 2011, the surface air temperature in China has shown a clear increasing trend. And if this trend continues, the average temperature will increase by 1.3-5.0℃ by 2100. During 1980 to 2012, the rate of sea level rise was 2.9mm/yr. The sea level will rise by 0.4-0.6m by 2100. Over the last century, no obvious change in annual precipitation in China has been detected, but evident variations among regions have been recorded. As projected, annual precipitation will increase by 2-5% by the end of this century, but this is not likely to reduce water shortage problems. Rather, China's water resource might be cut by 5% by climate change. The frequency and intensity of extreme weather events have changed significantly throughout China in the last half century, and this trend is estimated to be continued (Editorial Board of the Third National Assessment Report on Climate Change 2015). All these changes have, and will, continue to deeply impact the natural ecosystem and the social economic system in China, especially in urban areas where population, industry and wealth are highly concentrated.

More than 70% of large cities and more than 40% of the population are located in China's coastal areas that generate over 70% of total GDP but occupy less than 1/7 of the total territory of China (Liu and Han 2007, Wang 2014). However, these more developed and crowded regions are vulnerable to natural disasters related to climate change, such as cyclone activities and floods. As Organization for Economic Cooperation and Development (OECD) reported, a number of Chinese cities, including Guangzhou, Shanghai, Tianjin, Ningbo, Hong Kong and Qingdao, were ranked amongst the top 20 cities in terms of population and assets exposed to coastal flooding in 2070s (Nicholls, Hanson et al. 2007).

As the biggest carbon contributor worldwide, meanwhile one of the most vulnerable countries, China is tasked with responding to climate change. In 2009, the Chinese leadership made a clear commitment of transition to a low-carbon growth path that could reduce carbon intensity of GDP by 40-45% by 2020 from a 2005 baseline. Chinese cities present an opportunity for such a transition since they are politically, financially, and administratively organized to enact policies quickly to meet the carbon emission reduction goal (Baeumler, Ijjasz-Vasquez et al. 2012). Today, in response to this development transition, numbers of cities are already developing low-carbon city initiatives. As the Chinese Society for Urban Studies reported, until February 2011, 259 cities above prefecture level have declared the intention of becoming an “eco-city” or “low-carbon city”, accounting for over 90% of all prefectural cities (Chinese Society for Urban Studies 2011).

1.4 Research objectives

Given the CO_2 intensity reduction goal, low-carbon city development becomes an inevitable target for Chinese cities. However, though numbers of cities have shown considerable interest in developing a low-carbon city, there is still no consistent definition of the concept “low-carbon city”, and no evaluation method to determine if a city meets the requirements and definition. This makes the low-carbon city development lose its direction and become unmeasurable, which hinders the low-carbon progress in Chinese cities. Therefore, there is an urgent need to define the term “low-carbon city” and to develop a scientific and feasible evaluation framework in order to evaluate a city’s current situation and measure progress toward more low-carbon development.

Accordingly, the objectives of this work are fourfold:

- To clarify the connotation and definition of the “low-carbon city” through researching the theory from its origins. To discuss the insufficiencies of the existing research achievements of low-carbon city evaluation and the research space for this work, on the basis of the review of the research background of low-carbon city and low-carbon city evaluation.

- To systematically investigate six key urban sectors “urban design”, “transport”, “energy”, “building”, “water”, and “municipal solid waste” which are closely related to climate change, and explore climate mitigation and adaptation strategies for each of the sectors, on the basis of the analysis of carbon emission contribution and climate risk of these sectors, so as to indicate the orientation of low-carbon city development.

- To construct an evaluation system for low-carbon city evaluation in China, on the basis of coupling urban planning with key urban sectors that offer cities great potential for carbon reduction and resilience enhancement.

- To test the use of this low-carbon city evaluation system through a case study, in order to examine its validity and operability.

1.5 Thesis outline

This thesis contains six chapters and is organized in the following way:

Chapter One, Introduction, introduced the research background, emphasized the important role cities play in climate change mitigation and adaptation by deeply studying the relationship between cities and climate change, and then discussed China's contribution to global carbon emissions and its climate risk. On this basis, this chapter identified the research objectives and briefly stated the organization of the thesis.

Chapter Two, Low-Carbon City and Evaluation, explored the derivation of the concept "low-carbon city", and introduced a definition of low-carbon city that highlights climate mitigation and adaptation as two key points of city development. After that, this chapter reviewed the research situation of the theory and practice of low-carbon city and low-carbon city evaluation. Finally, the limits and prospects for research on low-carbon city evaluation were analyzed in chapter two.

Chapter Three, Key Sectors of Low-Carbon City Evaluation, introduced the significance of urban sectors "urban design", "transport", "energy", "building", "water", and "municipal solid waste" in low-carbon city evaluation. And then, it further analyzed the carbon emission contribution and climate risk of each sector, and proposed the corresponding mitigation and adaptation strategies. On this basis, evaluation aspects of all sectors were determined.

Chapter Four, Development of Low-Carbon Indicator System – Sino, intended to develop an evaluation method for low-carbon city – Low-Carbon Indicator System – Sino (LCISS). The evaluation framework, mode, function, products of LCISS, the process of LCISS construction, and the introduction of indicators were detailed in this chapter.

Chapter Five, A Case Study of Sino-Singapore Tianjin Eco-City, examined the use of LCISS through the case study in Sino Singapore Tianjin Eco-City (SSTEC). This chapter firstly explained the background of the project SSTEC, and then introduced the application process of LCISS, and finally discussed the evaluation results.

Chapter Six, Conclusion and Future Work, summarized the contents, discussed the contributions and pointed out limitation and future work of this thesis.

Chapter 2 Low-Carbon City and Evaluation

2.1 Concept of low-carbon city

2.1.1 Origins of low-carbon city

The concept of "low-carbon" ("carbon" here refers to the "carbon dioxide equivalent") was put forward under the background of global climate change and increasing energy consumption and greenhouse gases (GHGs) emission. The early exploration started with the research of low-carbon economy. This idea firstly entered into people's horizons in the United Nations Framework Convention on Climate Change (UNFCCC) in 1992. The term "low-carbon economy" was formally proposed in a British Energy White Paper "Our Energy Future: Creating a Low Carbon Economy" in 2003. In this book, low-carbon economy was defined as an economic development model which has higher resource productivity - producing more with fewer natural resources and less pollution - will contribute to higher living standards and a better quality of life, and will provide opportunities to develop, apply and export leading-edge technologies, creating new businesses and jobs (Department of Trade and Industry 2003).

The proposal of "low-carbon economy" has aroused world-wide attention. Under this background, more relative researches have been carried out. Since 2004, the government and scholars in Japan started the research of the model and path towards low-carbon society, and the term "low-carbon society" was initially brought forward in the Japan-UK joint research project on "Sustainable Low Carbon Society" ("2050 Japan Low Carbon Society" scenario team 2008). The core content of low-carbon society is: on one hand, to increase energy utilization efficiency by using low-carbon energy sources and technologies, and on the other hand, to minimize energy consumption and GHG emissions through promotion of low-carbon and sustainable consumption concept and lifestyle (Cai, Wang et al. 2012).

Although "low-carbon economy" and "low-carbon society" share the goal of reducing carbon emissions, they have different emphases. Specifically, low-carbon economy focuses on mitigation of carbon emissions from industrial production, while low-carbon society highlights a shift of consumption style and behavior pattern towards low levels of emission. On this basis, with the deepening of low-carbon development research, another idea "low-carbon city" is derived. It refers to cities, the center of human activities, as the "main battlefield" of mitigation and adaptation actions to address climate change, and carries out "low-carbon" concept in the process of urban development.

Although the term "low-carbon city" is new, the concept has profound origins in theory. From the ancient Chinese ecological concept of "the integration of heaven and man" to the theory of Howard's garden city in the late 19th century, to the eco-city concept in the 1970s and sustainable development theory in the 1980s, then to smart growth movement in the 1990s, numerous theories have shaped the debate about low-carbon city concepts.

(1) The integration of heaven and man

In traditional Chinese culture, "the integration of heaven and man" is the representative of the ecological concept of harmony between nature and human (Ji 1993). This ancient ecological awareness holds that human beings and all things in nature are equal, which opposes the "human-centered" view of nature. It takes the relation of humanity, society, and nature as an organic unity of interaction and these elements impact, constrain, and interact with each other mutually, every part is similarly constituted and governed by the same rules (Zhou, He et al. 2012). The harmony between the city and surrounding environment is one of the core characteristics of low-carbon city.

(2) Garden city

Garden city is a method of urban planning that was first put forward by Ebenezer Howard in 1898. Garden cities were intended to be planned, self-contained communities surrounded by "greenbelts" (parks), and containing proportionate areas of residences, industry, and agriculture (Lucey 1973). The working emphasis of garden city development – optimizing parks and green spaces in the city, is also an important task of creating low-carbon cities.

(3) Sustainable development

The concept of sustainable development was initially presented by the United Nations World Commission on Environment and Development (WCED) in its 1987 report "Our Common Future". It is a development idea formed on the basis of respecting nature and coordinating environment with development, which represents a great progress in the viewpoint of human development. As a commonly used definition, sustainable development is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland Commission 1987).

Theory of low-carbon city is a branch of the theory of sustainable city development, which aims to achieve sustainable urban development under the background of global climate change by taking energy consumption and environmental impact as main research objects.

(4) Eco-City

The idea of an ecological city (eco-city) was born in the implementation of a programme of United Nations Educational, Scientific, and Cultural Organization (UNESCO) on Man and the Biosphere (MAB) in the 1970s. It aims to improve the well-being of citizens and society through integrated urban planning and management, harnessing the benefits of ecological systems while protecting and nurturing them for future generations (Suzuki, Dastur et al. 2010). Despite divergent views on the definition of eco-city, all related studies show a common development goal of eco-city: harmonious development of society, economy and nature.

The concepts of eco-city and low-carbon city are interconnected and overlap each other (Chen and Lu 2010). Energy use and carbon cycling are the research focuses of both theories, while the research span and spatial scale of each are different.

(5) Smart growth

Smart growth, an urban and transport planning theory, has arisen in the USA since the early 1990s. It concentrates new development and redevelopment in compact walkable urban centers to prevent urban sprawl. Smart growth is a sustainable development mode, focusing on compact city design, mixed-use development and transit-oriented development (TOD) by integrating transportation and land use. These approaches could effectively limit the urban sprawl and, in turn, lower the city's comprehensive energy consumption and associated carbon emission. This has a great alignment with spatial development strategy of low-carbon city.

2.1.2 Definition of low-carbon city

Despite the extensive research that has been done in the past decade, it remains unclear what defines a low-carbon city. Through the literature retrieval on Google Scholar with "low carbon city" as keywords, there were 4610 results by 2014, while ten years before, in 2005, this number was only 33. In most of the research, "low-carbon city" is recognized as a city that leads to low-carbon economics and society, which cuts GHG emissions in ways that are not at the expense of economic development and livability (Fu, Wang et al. 2008, Xia 2008, Xin and Zhang 2008, Zhuang 2008, Dai 2009, Liu, Dai et al. 2009, Zhu 2009, A. Wang 2010, J. Wang 2010, Li and Zhang 2010, Qin, Zhang et al. 2010, Zhang, Ye et al. 2010, Zhu and Chen 2010, Baeumler, Ijjasz-Vasquez et al. 2012). According to the Climate Group, low-carbon city promotes and implements low-carbon economy to achieve low carbon emission, or even zero carbon emission in the scope of a city through transitional efforts on four aspects: economic development, energy structure, consumption pattern, and carbon intensity (The Climate Group 2009). In the Chinese government report "2050 China Energy and CO_2 Emissions Report", low-carbon city refers to a city that adopts low-carbon economy as its developing model and orientation, low-carbon life as citizens' consumption and behavior pattern, and low-carbon society as government's blueprint of urban construction (The Research Group of 2050 China Energy and CO_2 Emissions 2009). From these definitions given by authorities, it can be seen that currently the definition of a low-carbon city is still relatively general and vague, and with a strong emphasis on mitigation action but not enough on adaptation action.

Actually, adapting to climate change has equal importance as reducing the anthropogenic causes of climate change (Parry, Canziani et al. 2007). The IPCC Fourth Assessment pointed out that “no mitigation efforts, no matter how rigorous and relentless, will prevent climate change from happening in the next few decades” (Klein, Huq et al. 2007). Thereby, climate mitigation and adaptation play the same significant role in low-carbon city development.

Based on the above discussion, this work adopted the definition of low-carbon city from the book “Towards a Low Carbon City – Focus on Durban” (ASSAf 2011), which is described as follows:

“A low-carbon city is one that strives to reduce its GHG emissions and increase its carbon sinks, while simultaneously adapting to the anticipated climate change impacts.”

In this definition, two key points of low-carbon city development, climate mitigation and adaptation, are of equal significance.

2.2 Research progresses of low-carbon city

2.2.1 Theoretical research

Low-carbon city, as the key to addressing climate change challenges, has been extensively studied. At present, the research on low-carbon city mainly focuses on driving factors of carbon emissions in urban area, carbon cycle and metabolism of urban system, urban planning of low-carbon city, and framework and route for low-carbon city.

In urban areas, four driving factors influence the GHG emissions: population growth, economic development, urbanization, and energy efficiency. According to the existing research results, the population has obviously positive correlation with carbon emissions, i.e. population growth could drive an increase in carbon emissions (Malthus 1967, Boserup 1981, Martínez-Zarzoso, Bengochea-Morancho et al. 2007, Dai and Zhao 2014). GDP per capita, as measurement of economic development, is also positively related to carbon emissions. However, at different stages of development in city, the relation between per capita GDP and carbon emissions can exhibit several forms, such as inverted-U shape (He and Richard 2009), N shape (Martínez-Zarzoso and Bengochea-Morancho 2004), and linear (Galeotti, Lanza et al. 2006). In the process of urbanization, owing to the change of forms and functions of the city, the timing aggregation, spatial distribution, and composition of carbon emissions could be altered (Lebel, Garden et al. 2007). Thus, there is a positive correlation between the urbanization level and carbon emissions (Sustainable Development Strategy Study Group Chinese Academy of Sciences 2009, Sun, Jin et al. 2013). Research on the relationship between energy efficiency and carbon emissions indicated a negative correlation between them, which means that emissions could be mitigated by improving energy efficiency. With the progress of low-carbon technology, energy efficiency has been greatly enhanced. This directly affects the level and cost of carbon emissions from the fields of production and consumption (International Energy Agency-IEA 2009, Strachan, Pye et al. 2009).

Research into the carbon cycle and metabolism of urban systems mainly focuses on lateral and vertical carbon flux (Churkina 2008). A study of 29 of the largest cities in Baltic Europe suggested that the range of a city's carbon recycling system is much larger than the area of the city, which could be extended to hundreds of kilometers away (Folke, Jansson et al. 1997). For the vertical carbon flux in urban areas, soils are the major carbon reservoir: the plants in green spaces absorb carbon dioxide and release oxygen, and fix carbon on the vegetation and soil through photosynthesis (Jenks and Jones 2009). Thereby, urban green spaces are an important carbon sink that soak up and store CO_2 (Jo 2002). The process of urban development and expansion significantly affects the carbon cycling in urban plants and soils (Pataki, Alig et al. 2006), and causes alterations of vertical carbon cycle. The studies of lateral carbon flux in urban areas mainly focus on direct and indirect human-generated carbon emissions, and emissions over the full life cycle of products (Wiedmann and Minx 2008). Activities, such as trade, service, material flows could have significant influence on the lateral carbon cycle (Qin, Zhang et al. 2010).

Discussions of strategies of urban planning targeting low-carbon development were heavily focused on compact urban form, transit oriented development (TOD), and mixed land use (Gu, Tan et al. 2010). These three strategies are organic wholes which are connected and promoted mutually (Petersen 2004, Wright 2005-3a, Yokota, Hansen et al. 2012). Specifically, compact urban form is the key to energy consumption and carbon emissions control in a city (Dieleman, Dijst et al. 1999), and it could be achieved by implementing TOD and smart mixed land use (Kii and Doi 2005, Shim, Rhee et al. 2006). A series of studies showed that i) urban development density is strikingly correlated to carbon dioxide emissions that low-density development is associated with more CO_2 emissions than higher density construction (Glaeser and Kahn 2010); ii) with a focused TOD growth strategy, a city could significantly reduce future VMT-related GHG (Haas, Miknaitis et al. 2010); iii) smart mixed land use could reduce the demand for motorized mobility by keeping distances short, thus reducing the associated emissions (Fong, Matsumoto et al. 2008). Furthermore, the representative low-carbon city planning concepts and models include Jabareen's seven design concepts and four types of urban forms (Jabareen 2006), Rickaby's six settlement patterns (Rickaby 1987), and Kenworthy's ten key transport and planning dimensions (Kenworthy 2006).

In terms of achieving low-carbon city development, there are three main routes: spatial structure, technology, social policy and institution (Chen and Lu 2010).

Urban spatial structure has a fundamental influence on the city's energy consumption and CO_2 emissions. As has been widely documented, different urban forms (measured in terms of residential densities, job concentration, and mix of land uses) require different amounts of land for accommodating similar amounts of population and activities, resulting in different levels of energy consumption and CO_2 emissions (Newman and Kenworthy 1989, van de Coevering and Schwanen 2006, Chen, Jia et al. 2008, Liu and Salzberg 2012). Moreover, urban form has a "lock-in effect" on the generation of CO_2 (Pan, Tang et al. 2008).

Technology is one of the key factors affecting energy efficiency and energy structure. Application of low-carbon technology in the sectors of building (Ürge-Vorsatz, Danny Harvey et al. 2007), energy, and transport (Moll, Noorman et al. 2005) are important means to mitigate carbon emissions (Chen and Zhu 2009). In addition, technological change could also reduce the costs of CO_2 abatement (Manne and Richels 2004).

Policy, social mechanism, and life-style could influence energy consumption and carbon emissions of a city too. Emissions reduction policy and mechanism involves i) marketing approach, such as carbon trading; ii) controlling approach, such as establishing limits and standards of CO_2 emissions; iii) fiscal approach, such as setting up energy-, environment-, and emission-related taxes and subsidies (Chen and Lu 2010). A low-carbon life style and consumption pattern are also practical ways citizens can aid carbon mitigation. A recent study analyzed the personal share of the UK's carbon emissions in detail (Goodall 2010). The results highlighted the essentiality of individual actions dealing with climate change for low-carbon development and provided a guide of a low-carbon life.

2.2.2 Practical research

The low-carbon city development might be essential to respond to the pressing issue of climate change, thus, the practice of low-carbon city has been outspread in many countries worldwide. Some cities have developed their own "low-carbon" action plans, such as the famous London, Stockholm, Copenhagen, etc. (Table 2.1). At present, experiences of low-carbon city development for reference are mostly from the programmes organized by international networks and initiatives on climate change, such as C40 Cities Climate Leadership Group, Local Governments for Sustainability, etc. Some of the representative programmes, to name a few, are as follows:

Climate Leadership Group's C40 Initiative[5] launched in 2005 as a network of 18 megacities, and has since expanded to include 75 cities around the globe. It is a network

[5] http://www.c40cities.org/

of the world's megacities taking action to reduce GHG emissions. The member cities involve famous world cities, such as New York City, London, Tokyo, Paris etc., remarkably, Beijing, Shanghai, Hong Kong, Shenzhen, and Wuhan, five Chinese cities are also involved.

ICLEI- Local Governments for Sustainability[6] was founded as the International Council for Local Environmental Initiatives by the United Nations in 1990. ICLEI is an international association of over 1,000 cities, towns and metropolises that aim to build and serve a worldwide movement of local governments to achieve tangible improvements in global sustainability, with a specific focus on environmental conditions through cumulative local actions.

The World Mayors Council on Climate Change – WMCCC[7], founded in 2005, is an alliance of committed local government leaders concerned about the protection of climate change. It aims for enhanced engagement of local governments as governmental stakeholders in multilateral efforts addressing climate change and related issues of global sustainability. Presently, there are over 80 members of the WMCCC.

The Climate Alliance[8] of European Cities with Indigenous Rainforest Peoples is an association of local authorities created in 1990 that have committed to the protection of the world's climate. The Climate Alliance's more than 1700 member municipalities throughout Europe have committed themselves to reduce GHG emissions at their source.

The Asian Cities Climate Change Resilience Network[9] was launched by the Rockefeller Foundation in 2008 with a focus on 10 Asian cities, and has since expanded to over 50 cities. It aims to promote partnerships, funding, and action for enhancing climate change resilience of vulnerable people, institutions and systems to prepare for, withstand, and recover from the anticipated impacts of climate change.

The Covenant of Mayors[10] is a European initiative involving local and regional authorities. By 2015, the Covenant of Mayors has 6289 signatory towns and cities around Europe. The signatories voluntarily commit to reduce CO_2 emissions through increasing energy efficiency and use of cleaner energy sources. By their commitment, they support the European Union to reach the 20% CO_2 reduction objective by 2020.

In addition to the above low-carbon city initiatives, globally, many communities, cities, countries and organizations are developing and practicing climate action plans. These various experiences of implementing low-carbon development worldwide provide multiple perspectives for interpreting sustainable development in the context of climate

[6] http://www.iclei.org
[7] http://www.worldmayorscouncil.org
[8] http://www.climatealliance.org
[9] http://acccrn.net
[10] http://www.covenantofmayors.eu

change.

Table 2.1 Climate action plans and development experiences from representative cities

City	Urban planning/action plan	Development strategy and experience
Manchester	Manchester City Council's Climate Change Delivery Plan 2010 – 2020	The major low-carbon initiatives involve: retrofit public and commercial buildings and housing to improve the energy efficiency; induce low-carbon energy infrastructure; develop integrated transport strategies, provide efficient public transportation service; facilitate new and alternative modes and fuels of transport; adopt a zero waste policy by 2020; provide information and training for residents and employees across the city through the programme "carbon literacy"; green the city by developing green spaces, installing green roofs and facades in the city centre.
New York City	PLANYC 2030	NYC's climate protection plan targets a 30% emission reduction of GHGs by 2030 from its 2007 baseline. The key actions involve: improve energy efficiency in existing buildings and reduce the use of heavy heating oils; strengthen its building code; develop the use of cleaner energy and renewable energy; green the city by maintaining and expanding green spaces; improve public and non-motorized transport systems; facilitate electric vehicles and alternative fuels; heighten resilience measures to protect critical utility facilities from climate risks.
London	The Mayor's Climate Change Action Plans	London's core CO_2 reduction strategies include the following: improve the energy efficiency of residential and other buildings by investing decentralized energy infrastructure; improve waste and recycling infrastructure; green the city's public spaces; promote low carbon economy; facilitate more hybrid buses.
Tokyo	Tokyo Climate Change Strategy - A Basic Policy for the 10-Year Project for a Carbon-Minus Tokyo	Tokyo is the world's first city to implement a Cap and Trade Programme for reducing carbon emissions. In addition, a number of ideas for future climate actions were devised: make carbon mitigation mandatory for business operations; strengthen energy

		efficiency standards for new buildings; create a system to provide consumers with information on energy efficiency; curb emissions from road traffic; promote the utilization of renewable energy; consider measures tackling the heat island effect as part of urban planning.
Freiburg	Freiburg Climate Protection Strategy 2030	Freiburg is renowned as a “Solar Region” and a “Green City”. Through a combination of energy savings, energy efficiency and renewable energy, the reduction of energy consumption in Freiburg is considerable. Its climate protection action plan involves: improve renewable energy utilization through encouraging combined heat and power plants in public buildings and schools; implement energy efficient renovation of municipal buildings; emphasize the importance of municipal leadership and community involvement; promote non-motorized mobility, particularly bicycle and pedestrian traffic.
Hong Kong	Green Hong Kong • Carbon Audit	Hong Kong’s climate change strategy aims to reduce 25% GHG emissions from 2005 levels by 2030. The action agenda includes: maximize energy efficiency at buildings through reducing energy demand of major electrical equipment; promote use of electric vehicles and alternative fuels, and strengthen energy efficiency standards for vehicles; promote the use of renewable energy sources or energy from waste; increase the utilization of non-fossil, clean and low carbon fuel for power generation.
Toronto	Climate Change, Clean Air and Sustainable Energy Action Plan: Moving from Framework to Action	The GHG reduction targets of Toronto are, from the city’s 1990 baseline, 6% emission reduction by 2012, 30% by 2020, and 80% by 2050. Its climate change actions include: engage the citizens, community groups and businesses to reduce energy consumption and associated emissions through “Live Green Toronto” programme; retrofit the concrete high-rise residential buildings; invest in residential solar hot water heating; develop a

		website to provide consumers with information on energy efficiency and environment; promote local food production, community gardens, and community energy planning; provide incentives to encourage the use of low emission or hybrid vehicle technology.
Seattle	Seattle Climate Action Plan	Seattle’s major climate actions contain: expand transportation options to divert from car-dependence; encourage non-motorized transport by improving bike and pedestrian infrastructure; facilitate hybrid and electric vehicles and alternative fuels; promote solar and other alternative energy sources; provide residents and businesses with the tools to improve energy efficiency in buildings; highlight the importance of community engagement.
Copenhagen	CPH Climate Plan	The city of Copenhagen has a vision of becoming the world’s first carbon neutral capital in 2025. Its mitigation actions generally include: aim to achieve 10% of total CO_2 reduction through building redesign and construction projects by 2015; 97% of the city heating is supplied by a system capturing waste heat; develop high quality public transport system and cycle path system. In addition, its adaptation actions contain: reduce the risk of flooding by implementing various methods of water draining, and green roofs and facades that slow rainfall runoff; improve the ventilation and insulation of buildings.
Stockholm	Stockholm's Action Programme on Climate Change	Initiatives in Stockholm toward mitigating carbon emissions include: re-design and construct buildings to improve energy efficiency; adopt district heating and heat pumps, and promote the use of renewable energy sources or energy from waste or residual waste heat; encourage use of clean vehicles.
Curitiba	Accelerate the Transition to Sustainable Communities and Societies	The city is recognized as one of the most sustainable cities, which is best known for its innovative urban planning and management, and sustainable transport. Even Curitiba is a

		densely populated city, the importance of green areas is highlighted. The city is dominated by an integrated Bus Rapid Transport (BRT) system. Furthermore, all public buses in Curitiba run on biofuels instead of fossil fuels.
Yokohama	Yokohama City Action Plan for Global Warming Countermeasures	Yokohama's carbon reduction target is over 30% per capita by 2025 and over 60% by 2050 from 2004 levels. The detailed action plan mainly includes: improve energy efficiency of commercial buildings and households through support of energy-saving products, promoting low-carbon buildings; reduce emissions from transport sector through improving public and non-motorized transport systems, implementing traffic demand management, promoting fuel-efficient and electric vehicles; and increase the consumption of renewable energy ten-fold by 2025 from the 2004 levels.

Source: (ASSAf 2011, Global Carbon Project 2011, C40 Cities Climate Leadership Group 2015)

China has committed to reducing its CO_2 emissions per unit of GDP by 40 to 45% by 2020 during COP-15, compared with the 2005 baseline. Cities are an integral part of this reduction, thus "low-carbon" has become the main concern in the new round of urban development in China. In the past, numbers of cities have shown considerable interest in developing a low-carbon city. According to statistics reported by the Chinese Society for Urban Studies, till February 2011, 259 cities above prefecture level have declared the intention of becoming an "eco-city" or "low-carbon city", accounting for over 90% of all prefectural cities (Chinese Society for Urban Studies 2011). Among them, representative cases include the eight cities of the "Low-Carbon Pilot City" program that launched in 2010 by the National Development and Reform Commission (NDRC) (Table 2.2) and demonstration projects, such as Sino-Singapore Tianjin Eco-City, Shanghai Dongtan Eco-City and Hongqiao Low Carbon Business Center, Tangshan Bay Eco-City, Shenzhen Guangming New District, Baoding "Electricity Valley" and "Solar City" (Table 2.3).

However, despite these efforts, the practical research of low-carbon city in China is still in its infancy, usually spontaneous, unsystematic, and tentative. At the central government level, there is still an insufficiency of detailed and rigid climate protection standards in macroscopic planning, thus low-carbon city development strategies lack of systematicness and binding force. At the local government level, low-carbon development model and planning of most Chinese cities are not able to embody and reflect their own characteristics, such as development stage, population size, resources endowment and industrial structure. A number of cities simply copied the Baoding model in which new energy and low-carbon industry plays a leading role, and the demonstration project model, which was represented by Sino-Singapore Tianjin Eco-City.

To meet the emission target, China should on one hand introduce absolute CO_2 emission control in its macroscopic development strategy (five-year plan), which could provide more targeted development time schedule and route plan to the future climate mitigation and adaptation actions (Wang 2015); on the other hand, municipal governments should adopt advanced experiences of the pilot projects, but formulate their own low-carbon development strategies corresponding to the actual situation instead of simply copying (Li, Ma et al. 2011).

Table 2.2 Low-carbon plans for eight pilot cities

City	Action plan	Issue date	Drafting institution
Baoding	Baoding city people's government views on building low carbon city	12.2008	Baoding Municipality Government
Hangzhou	Hangzhou city people's committee and government views on building low carbon city	12.2009	Hangzhou Municipality Government
Xiamen	The overall planning framework for low carbon city of Xiamen	01.2010	Xiamen Construction & Administration Bureau
Tianjin	Tianjin's climate change program	03.2010	Tianjin Development and Reform Commission
Guiyang	Guiyang city low carbon development action plan framework (2010-2020)	07.2010	Guiyang Municipality Government
Nanchang	The action plan for Nanchang low carbon pilot city	11.2011	Nanchang Municipality Government
Shenzhen	Medium- and Long-term plan for Shenzhen low carbon development (2011--2020)	02.2012	Shenzhen Development and Reform Commission
Chongqing	The action plan for Chongqing low carbon pilot city	03.2012	Chongqing Development and Reform Commission

Source: (Khanna, Fridley et al. 2013)

Table 2.3 Development concepts and experiences from low-carbon cities demonstration projects in China

City	Project	Development concept and experience

Tianjin	Sino-Singapore Tianjin Eco-City	The development concept of Sino-Singapore Tianjin Eco-City involves: establish an industrial system on the basis of circular and low-carbon economy; form an integrated landscape system comprising lake, river, wetland and greenery; construct an efficient green transportation system; promote alternative energy technologies and raise energy efficiency; develop a livable and friendly community mode. It is expected to be the most successful demonstration project in China.
Shanghai	Dongtan Eco-City	Dongtan Eco-City is China's first Eco-City project that has been credited for its planned zero-carbon footprint. Its development concept focuses on development of new energy, environmentally friendly buildings, and green transportation system. Since 2009, the project has been shelved.
	Hongqiao Low Carbon Business Center	The development concept of Hongqiao project includes: adjust industrial structure to develop low-pollution low-carbon industry; limit the urban sprawl; encourage mixed land use; and establish public and non-motorized transport oriented transportation system.
Baoding	"Electricity Valley" and "Solar City"	The development target of Baoding is to establish six industry clusters of wind power, photoelectricity, electricity conservation, electricity storage, electricity transmission and transformation and electric automation. Other key actions of low-carbon city construction include urban ecological environment construction, low-carbon community construction, low-carbon public building construction, and low-carbon transportation system construction.
Tangshan	Tangshan Bay Eco-City	An eco-city indicator system with 141 indicators in 7 categories was developed by Tangshan Bay Eco-City. It is used to guide the development in the field of urban function, building and construction industry, traffic and transportation, energy, waste, water, and landscape and public space. Its development focus is on resource conservation, green buildings, city security, recycling economy, green transportation, renewable energy, lifestyle, cultural integration, and highly efficient public utilities. Because of the reorientation and capital constraints, the progress of this project is slow.

Shenzhen	Guangming New District	The core concept of the low-carbon planning of this project includes: optimize the urban space structure; adjust industrial structure, and develop low-carbon economy; establish green transport-oriented transport system through implementing TOD model; develop green buildings.

Source: Author based on (Tang, Liu et al. 2009, Li, Ma et al. 2011, Zhou, He et al. 2012)

2.3 Low-carbon city evaluation

With the development of the "Low-Carbon City" theory and practice, evaluation of low-carbon city, as the key to realizing low-carbon development has gradually become a new hotspot in this research field. Various methods and models have been applied in the research of low-carbon city analysis and assessment, with a great deal of achievement. The main methods include: Decomposition Analysis (DA) models, carbon footprint analysis models, low-carbon city planning relevant models, and low-carbon city environmental governance models.

Decomposition Analysis models are a widely used tool of analysis of drivers of CO_2 emissions in urban areas, mainly including Index decomposition analysis (IDA) and Structural Decomposition Analysis (SDA). IDA is a static and comparative methodology that uses aggregate data at the sector-level. Through the implementation of IDA, the information of energy/emission indicators gathered at different levels of the energy/emission hierachy can be appropriately used to the greatest extent (Xu 2013). Its common methods are Adaptive Weighting Decomposition (AWD) (Liu, Ang et al. 1992), Laspeyres index (Park 1992), the Simple Average Decomposition (SAD) (Ze, Xu et al. 2006), Logarithmic Mean Divisia Index (LMDI) (Zhao, Huang et al. 2015), and etc. SDA is a comparative-static technique with a very detailed input–output analysis. Utilizing a SDA, it decomposes the change in carbon emissions into several determinants such as input/output coefficient, final demand mix, industrial efficiency, etc. (McGregor, Swales et al. 2008).

Studies of carbon footprint analysis have also been receiving more attention. Major methods are as follows: i) Life Cycle Assessment (LCA) model, is a technique that mainly analyses the mass and energy flows of a specific product's life from cradle to grave (Tukker 2000); ii) Environmental Input-Output (EIO) model, it is used to calculate carbon footprints on the basis of availability of persistent environmental data (Leontief 1970, Wiedmann, Minx et al. 2006); iii) Hybrid-EIO-LCA model, is a combination of the above two methods that integrates advantages of both, but with high operation complexity and reliability on good and detailed data (Heijungs and Suh 2006).

Relevant low-carbon city planning models can be broken down into three types: Scenario Analysis, System Dynamics (SD) model, and Cellular Automaton (CA) model. With the help of Scenario Analysis, the further development of a city can be forecasted, in turn, long-term scenarios for moving towards a low-carbon target can be designed (Shimada, Tanaka et al. 2007). SD models are often used in analysis and forecasting of the development trend of a city's energy consumption and CO_2 emissions (Fong, Matsumoto et al. 2007). CA models have enjoyed a wide application to the simulation of changes in urban spatial structure and land conversion, and estimation of carbon emissions (Li and Yeh 2000).

Environmental governance models are mostly used to analyze the cost-effectiveness of carbon emissions from aspects of energy economy, energy technology, energy consumption, environment, policy etc., and provide scientific basis for a city's energy strategy (Qin, Zhang et al. 2010). There are three representative methods: Long-range Energy Alternatives Planning (LEAP) system, Computable General Equilibrium (CGE) model, and Markal-Marco model. LEAP system regarded future energy demand and environmental impact as research objective, and analyzes the trends in energy consumption and carbon emissions of a city (Zhang, Feng et al. 2011). CGE model uses historical data to estimate how an economy might react to changes in policy, technology or other external factors. It provides insight into energy–economy–environment interactions and indicates opportunities for a low-carbon development (Kumbaroğlu 2003). Markal-Marco model is an integrated energy-environment-economy model that combines an integrated energy demand-supply model and a macro-economic model. It is widely used as the tool for low-carbon policy analysis (Chen 2005).

Although the low-carbon city evaluation is a new lesson in China, it is developing rapidly. Through the literature retrieval on China Knowledge Resource Integrated Database with "low carbon city" and "evaluation" as keywords, by 2014 there were 1641 results, while in 2007, this number was only 14. Most of the research is based on the studies of "eco-city evaluation" and "sustainable city evaluation". It is worth noting that in China "low-carbon city" and "eco-city" is often thought of as one combined concept, and widely applied to theory and practice studies. Currently, research achievements of low-carbon evaluation systems are generally in three forms.

(1) Evaluation systems developed by academic institutions or government departments, and issued in the form of research reports or evaluation standards.

In 2009, Objectives of Low-Carbon Urban Development Strategy in China (2009-2020) has been proposed by the Chinese Academy of Sciences (Wang 2009). It is established on the basis of three themes: economy, society, and environment, including 26 indicators (Appendix 1). In this evaluation system, low carbon development-oriented indicators, such as "Elasticity of energy consumption", "Usage of renewable energy", "Average walking distance to BRT stations", and "Forest coverage", have been selected.

In 2010, the Chinese Academy of Social Sciences launched the first evaluation criteria for low-carbon cities that consisted of 12 indicators, reflecting the situations of low-carbon productivity, low-carbon consumption, low-carbon resources, and low-carbon policy (Zhuang, Pan et al. 2011) (Appendix 2). In 2011, "China Low-carbon City Evaluation Index/Indicator System" was developed by Institute for Urban and Environmental Studies in Chinese Academy of Social Sciences in cooperation with Swiss Agency for Development and Cooperation (Institute for Urban and Environmental Studies Chinese Academy of Social Sciences 2013). It is composed of three parts: indicator list, low-carbon city assessment report, and action plans. As the key part, indicator list includes 15 major indicators and 50 supporting indicators (Appendix 3). This tool is developed through learning from the experience of European Energy Award, which functions as an action guidance to improve city's energy efficiency through staged improvements. Another evaluation system Urban Ecological & Livable Development Index-UELDI was developed in 2011 by Chinese Society for Urban Studies (Chinese Society for Urban Studies 2012). This system inspects both "soft" (behavior and process) and "hard" (result and effect) aspects to make full-process valuation on urban ecological construction. In accordance with the evaluation result, assessed cities are classified into four types: initial-stage city, developing-stage city, steady-stage city, and increasing-stage city (Figure 2.1). According to the UELDI results, the evaluated cities could find the key points, difficulties, risks of current ecological urban construction to find way to target future development. In September 2011, "Evaluation Index on Green and Construction for Key Small Cities & Towns (Trial)" was released by Ministry of Housing and Urban-Rural Development (MoHURD), Ministry of Finance (MoF) and National Development and Reform Commission (NDRC). This index includes 7 parts that are expressed as social and economic development; planning and construction and management; urban land use intensity; preservation of environment resources; decrease waste, energy saving, facilities and parks; public services level; and historical and cultural preservation. Within these 7 parts, 35 items and 62 indicators are involved (Appendix 4).

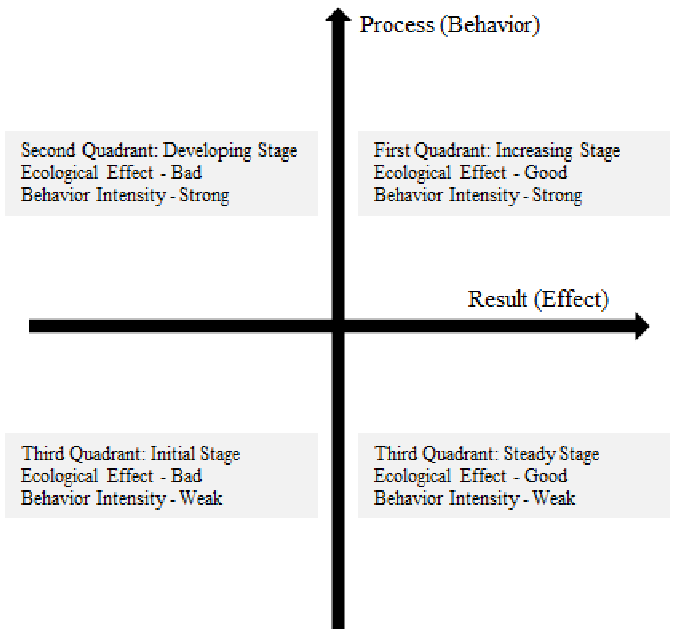

Figure 2.1 "Result-Process" structure of UELDI
Source: (Chinese Society for Urban Studies 2012)

(2) Evaluation systems set by local government or pilot demonstration urban project. Representative cases are as follow:

“Beijing Ecological Demonstration Area Evaluation Standard” was issued by Beijing Municipal Commission of Urban Planning in 2014. This standard consists of 8 parts of land layout, ecological environment, green transportation, energy utilization, water utilization, green building, informatization, innovation, containing 54 evaluation indicators (Appendix 5).

Sino-Singapore Tianjin Eco-City is a project implemented through international partnership of China and Singapore. As an important example of a low-carbon city project in China, it has set ambitious goals for cutting carbon dioxide emissions by 80% compare with the average emission level in cities of the same size. To guide the development of the Eco-City towards achieving the goals, 22 quantitative and 4 qualitative key performance indicators have been selected under four categories: ecological and healthy environment, social harmony and progress, dynamic and efficient economy, and integrated regional coordination (Appendix 6) (Sino-Singapore Tianjin Eco-City Administrative Committee 2008). The KPIs include explicit indicators of low-carbon city assessment, such as:

- KPI 5: Carbon emission per unit GDP: ≤150 ton-C per 1 million US dollars
- KPI 7: Proportion of green buildings: 100%
- KPI 12: Proportion of green trips: ≥90%
- KPI 13: Overall solid waste recycling rate: ≥60%
- KPI 19: Renewable energy usage: ≥20%
- KPI 20: Water supply from nonconventional sources: ≥50%
- KPI 22: Employment-Housing Equilibrium Index: ≥50%.

Currently, the KPIs have become an example that many other low-carbon city projects in China are anxious to study and imitate.

Another pilot project with much fanfare – Tangshan Bay Eco-City, which is a cooperation project between China and Sweden concerning eco-city planning theory and technology, has also established a set of characteristic evaluation systems. It consists of 141 indicators categorized into 7 topics: urban function, building and construction industry, traffic and transportation, energy, waste, water, landscape and public space (Appendix 7). The indicator system for Tangshan Bay Eco-City has been established on the basis of the SymbioCity integrated and multidisciplinary approach, which reflects the current Swedish development in planning theory and practice and has been adapted to the specific situation and challenges (Schylberg and Tan 2009).

Hongqiao Low Carbon Business Center is the best-practice project of urban planning in Shanghai. Through the Cooperative Project Shanghai: Integrated Approaches towards a Sustainable and Energy-Efficient Urban Development – Urban Form, Mobility, Housing and Living, an evaluation tool – Low Carbon Index (LCI®) has been developed by academics at the University of Duisburg-Essen. The evaluation process is divided into 3 phases, and examines the energy/CO_2 efficiency from 4 topics of urban design, mobility, buildings, and renewable energy, involving 75 criteria (Appendix 8). All criteria are evaluated on a scale from +2 to -2. There are different criteria – qualitative and quantitative ones – for each of the four topics. The LCI® evaluation results in a series of products (Checklists, Guidelines, and Design Codes) that may help diverse target groups in different stages and priorities of programs (Baltes and Schmidt 2010).

(3) Evaluation systems published in academic publications.

Since there is no universally accepted definition of low-carbon city, evaluation methods of low-carbon city have been developed on the basis of different understandings and emphases. Most studies are conducted from the following two perspectives:

· *Evaluation systems developed based on the analysis of the correlation of key elements of city development.* Such studies measure the carbon emissions from the carbon sources within urban areas, and perform statistical analysis of CO_2 emissions produced from urban social and economic activities according to different departments, thus to evaluate the low-carbon development level of a city (A. Wang 2010, Niu 2010, Price, Zhou et al. 2011). In addition, some scholars studied this issue in view of carbon reduction and carbon sequestration that on one hand emphasizes the absolute importance of reducing CO_2 emissions from the main carbon source such as industry, energy, transportation, building, and on the other hand also puts emphasis on enhancing carbon sink through construction of parks and forests (Chu, Ju et al. 2011, Lu, Tian et al. 2011, Zhang, Chen et al. 2011, Su, Li et al. 2013).

· *Evaluation systems constructed from the perspective of sustainable development.* Three pillars of sustainable development – economy, society, and environment are the core to these studies. In such studies, the key points of low-carbon city construction are generally selected as main evaluation objects and organized within a hierarchical structure. Moreover, criteria are calculated with specific calculation methods, such as Analytic Hierarchy Process – AHP method, Principal Component Analysis – PCA method, Delphi method, etc. (Fu, Liu et al. 2010, Ma, Zhou et al. 2010, Hua and Ren 2011, Wang, Zhou et al. 2011, Xin 2011, Xiong 2011, Yang 2011, Jiang and Zhang 2012, Lian 2012, Zhu and Liang 2012). There are also some academics who have established evaluation systems grounded on the “Driving force-Pressure-State-Impact-Response – DPSIR” framework, which analyze and evaluate low-carbon city in problem-driven mode (Shao and Ju 2010, Zhang, Wang et al. 2011).

2.4 Limits and prospects of research on low-carbon city evaluation

According to the reviews hereinbefore, scholars from different disciplines and fields have studied the low-carbon city from different approaches, and have come up with fruitful achievements. On the other side of the coin, owing to the differences in theoretical foundation, discipline background, and spatial scale between these researches, the findings cannot be easily integrated and applied. Thereby, further study should be more systematic and integrated.

In practice, many pilot projects have formulated their low-carbon development goals and strategy in light of their characteristics. Most of their actions focused on improving energy efficiency, adjusting energy structure, promoting green traffic systems and green buildings, and advocating low-carbon life and consumption etc. On the whole, while the low-carbon pilot cities are booming worldwide, the practice of low-carbon city is still at the stage of exploration.

At present, research of low-carbon city evaluation is still in its infancy. Most evaluation systems are developed in different disciplines. The evaluation objectives, functions, and applicable scopes vary from one to another. Thus, these achievements are not easily compatible and comparable. As mentioned above, in China, scholars have also made many beneficial attempts into this issue; however, there are still some insufficiencies:

- Insufficient evaluation on climate adaptability. In addition to climate mitigation concerns, separate and adequate attention should also be paid to adaptation of the evaluation of low-carbon city.

- Unadaptable to urban planning systems. In many Chinese cities, there is a disjunction between the low-carbon development strategy and the planning system. This in turn makes the low-carbon development poorly supported by the regular planning system. Consequently, the construction of low-carbon city becomes an armchair strategy. Furthermore, if the evaluation of low-carbon city is unable to evaluate a city's performance through various planning phases, the expected low-carbon goal will be difficult to guarantee.

- Lack of specific characteristics. The carbon-reduction potential and climate vulnerability vary from city to city, according to its size, natural environment, economy and social development. Accordingly, the actual situation of target cities should be taken into consideration as the evaluation system is developed.

- Confusion between "evaluation indicator" and "evaluation target". "Evaluation indicator" is different from "evaluation target". The development of evaluation indicator system is intended to monitor and assess a city's operational efficiency, and detect various efficiency-related problems (Li and Yu 2012). The evaluation target is normally an internal management tool set by resource allocation agencies, enforced by a higher level of management or external agencies (Li and Yu 2012), which can be used to check whether the target has been reached by a city, but not able to help a city to define the gap between the reality and the low-carbon development objective. It is important to note that, currently, the majority of low-carbon city evaluation system in China is evaluation target, with the evaluation indicator unsatisfactory.

The above shortcomings indicate the direction for this work:

- Paying equal attention to mitigation and adaptation. In a city's low-carbon development strategy, climate mitigation and adaptation are both significant. On one hand, without successful mitigation actions, the magnitude of climate change may be greater and make adaptation strategies ineffective (Blanco and Alberti 2010). On the other hand, without successful adaptation measures, even though the mitigation efforts are rigorous and relentless, climate change will not be prevented in the next few decades (Pachauri and Reisinger 2007). Hence, both mitigation and adaptation are indispensable in the evaluation of low-carbon city.

- Establishing a coupled model with low-carbon city evaluation and urban planning. In the frame of the Chinese urban planning system[11], urban planning includes overall plan, regulatory detailed plan, and site detailed plan that corresponds to macro, middle and micro planning scales. The development of low-carbon city is on the basis of urban planning, and involves "low-carbon" concept into different parts of planning with different focuses. Therefore, the evaluation of low-carbon city should be integrated with urban planning, in order to scientifically evaluate the city's low-carbon development level on different planning scales, and to indicate the inefficiencies.

- Emphasizing the specific and characteristic indicators. Since different cities have distinguishing features in terms of urban scale and form, natural environment, economic development level, carbon-reduction potential, etc., in low-carbon city evaluation research, actual situation of cities in different regions and provinces should be fully considered.

- Diagnostic evaluation. Low-carbon city development is a dynamic process. Thereby, compared to a static "evaluation target", a diagnostic evaluation could more accurately pinpoint the problems on different planning scales, and help cities to identify their strengths and weaknesses, so that they could better understand where improvement is needed in the future.

Based on the above analysis, this work intends to propose a new perspective of development of low-carbon city evaluation systems for Chinese cities and make empirical analysis through case study.

[11] Urban and Rural Planning Law of the People's Republic of China, Article 2 "…City or town planning includes overall planning and detailed planning. Detailed planning includes regulatory detailed planning and site detailed planning…"

Chapter 3 Key Sectors of Low-Carbon City Evaluation

As mentioned in earlier chapters, cities play irreplaceable roles in addressing the climate change issues that offer many options for low-carbon development, particularly in six key sectors: urban design, transport, energy, building, water, and municipal solid waste. Accordingly, these sectors are of significance to low-carbon city evaluation.

3.1 Urban design

3.1.1 Urban design and climate change

Urban form is the physical shape of a city, including the spatial and geographical layout of buildings and infrastructure (The World Bank 2011). Urban design is the most direct activity that affects urban form, which could be considered as significant implications for low-carbon city development. On one hand, urban form has considerable impact on energy use, resource consumption, and the climate change adaptation of a city. As has been extensively documented, different urban forms (measured in terms of residential densities, job concentration, and mix of land uses) require different amounts of land to accommodate similar amounts of population and activities, resulting in different levels of energy consumption and CO_2 emissions (Liu and Salzberg 2012).

On the other hand, urban design has a “lock-in effect” on urban form, and further on CO_2 emissions. Infrastructures and equipment generally have a long service life, which, once completed, should not be abandoned in a short-term. That means plenty of investments and technologies will be locked, and the resulting urban form may influence energy consumption and carbon emissions of a city for centuries. Therefore, managing the urban form through urban design is a critical area of intervention for addressing climate issues.

According to the relevant statistics, a majority of Chinese cities, especially central area of megacities are characterized by intense exploitation, high density and centralization (Figure 3.1). However, China is in the midst of the largest and most rapid process of urbanization the world has ever experienced. A huge amount of newly built cities or city areas may be locked into a high carbon pathway, if there is no regard for the important effects of urban form on energy consumption and CO_2 emissions, and a lack of correct guidance in development of building, transportation and energy. This can seriously hinder the low-carbon city agenda in the future. On the other side of the coin, urbanization brings opportunities to low-carbon city development in China as well. Taking climate problems into account in the initial capital and technology input phase may provide more significant potential for mitigation and adaptation to climate change.

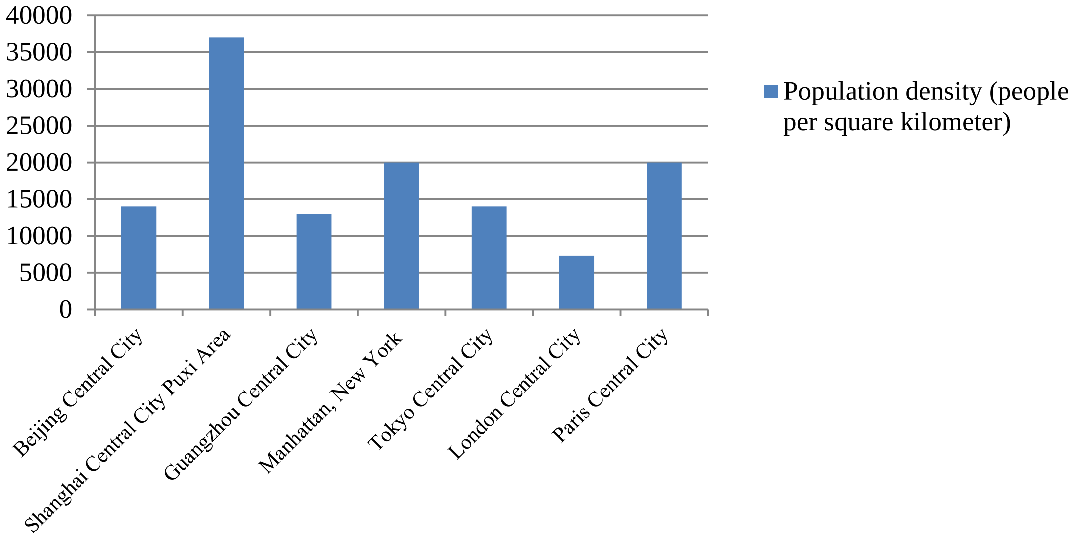

Figure 3.1 International comparison of urban population density
Source: (Editiorial Board of Annual Report on Urban Development of China 2004, Chen and Lu 2010).

3.1.2 Contribution of urban design to climate change

Urban Design determines whether the urban form influences CO_2 emissions positively or negatively, and to what extent. Transportation, building energy consumption and conversion of land use are the most crucial links between CO_2 emission and urban form.

Transportation – Previous studies showed that urban form impacts a city's CO_2 emissions through its interaction with urban transportation. It is a key factor in explaining patterns of automobile dependence and transportation energy consumption. Generally speaking, spatially compact and mixed-use urban development tends to shorten the trip distances and promotes utilization of the non-motorized and public transport, all of which could reduce the carbon emissions from urban transport. On the contrary, spatially-extensive (low density) urban development will cause larger emissions trough longer trip distances and higher share of private cars in transportation methods.

In the urbanization process in China, it is worrying that new growth in most cities takes the form of urban sprawl that refers to low density, dispersed or even decentralized forms of urban expansion (Blanco, McCarney et al. 2011). Chinese municipalities normally consist of a central city area and a large area of suburban districts or suburban counties. These suburban areas provide important land resource needed by urban development and urban population increment. However, since converting farmland into urban land can bring sizable financial gains, it becomes one of the most important sources of funds (Box 3.1). Municipal governments acquire rural land designated at rural land prices, then change it to urban land by improving urban infrastructures, and transfer its land use to developers for property development at higher rates. This large revenue makes a great incentive for the city leadership to develop city areas excessively and inefficiently, which often results in low-intensity, sprawled land use.

In addition to urban sprawl, the break-up of *danwei*[12] system has also contributed to the increase in trip rates and trip distances to an extent (Darido, Torres-Montoya et al. 2009). With China's economic transformation to market economy, the *danwei* system disintegrated gradually. Many urban residents no longer live where they work. As the commute distances extend, it leads to an increased demand on transport systems and levels of motorized transport activity, finally resulting in higher energy consumption and emissions.

Box 3.1 Municipal finance and land concessions

In 1994 China adopted a Tax Sharing System that provides separate tax-collection powers for the central government and subnational governments over certain categories of taxes. However, residential property tax and land value incremental tax, the main source of municipal revenue for many countries, have not yet been widely imposed in China. Currently, residential property tax collection has been piloted in Shanghai and Chongqing since early 2011.

The system is asymmetrically designed in the assignment of fiscal power and expenditures. It finally results in fiscal distress that local governments increasingly face the burden of rapidly growing expenditures without the power to raise tax revenues on the required scale. This gap between limited municipal budgetary revenues and growing expenditures is generally filled by off-budget funds. Land concession is the most important source of off-budget funds. In this context, municipal governments are forced to pursue financial gains from excessive conversion of farmland that contributes to excessive urban sprawl.

Source: (Liu and Salzberg 2012)

Building energy – Urban form is the general characteristics of a city's built environment. It can affect buildings' energy efficiency to a large extent. For every individual building, the surrounding streetscapes, green spaces and existing constructions can increase or reduce its demand for heating, cooling and electricity, which is associated with the level of CO_2 emissions in a city (see 3.4). For example, the green space or water space around a building will significantly moderate the heat island effect, thereby, reducing the energy consumption for cooling in summer days. Moreover, urban density, as a crucial factor of urban form, determines the size of living space per person. Compared with low density areas, compact housing is more

[12] The danwei, or work unit, was a walled compound organized around a state-owned enterprise or other institution such as a school or government agency which provides housing, entertainment, and other basic needs and services for its employees all reachable by walking distance.

low-carbon with less energy consumption for heating and cooling (UN-Habitat 2011).

Conversion of rural lands to urban use – Urban spatial development drives rural land conversion to urban uses, i.e. formerly farmland/forestland becomes incorporated within urban construction land. This change has a serious impact on climate change. On one hand, farmland and forestland have the ability to sequester and store carbon. The continuing encroachment on these carbon sinks will reduce the potential to absorb CO_2. On the other hand, the land that has been covered with natural vegetation replaced by impervious surfaced urban area will result in flux shift between the sensible and latent heat and related increases in thermal radiation (Blanco, McCarney et al. 2011), thus intensifying flooding and heat island effect. As described above, urban growth in Chinese cities is mostly sprawled, which causes severe damage to carbon sinks and strongly challenges the low-carbon city development in China.

3.1.3 Impacts of climate change on urban design

Climate change brings serious risks to urban citizens and activities. Such risks influence urban design through deciding the location of industry facilities, transport infrastructure, housing, green space and other investments, so as to ensure a city adapts to climate change.

As projected, the climate change impacts on cities typically include: temperature increases, precipitation changes, rising sea levels, and more frequent extreme weather events. Among them, flooding associated with rising sea levels poses a major risk for urban land, causing increased inundation of low-elevation areas in coastal cities, in turn, massive losses of valuable land and infrastructure (Hoornweg, Bhada et al. 2010). It is noted above that infrastructures and equipment attract a huge amount of investments and technologies, and normally have long service lives. Nonetheless, climate risks are estimated to be so high that, such facilities may have to be abandoned prematurely. Globally, low-elevation coastal zones (LECZ), which is defined as the contiguous area along the coast less than 10 meters above sea level, account for 2% of the world's area, but is home to 10% of the world's population and 60% of the urban population (Dickson, Baker et al. 2012). In China, LECZ takes 2% of total land area, where 23% of urban population lives and accounts for 14% of the total population (Procee and Brecht 2012). According to a study of OECD, China has the largest number of people exposed to coastal flooding today and in the 2070s, taking into account both future climate and socioeconomic changes (Nicholls, Hanson et al. 2008).

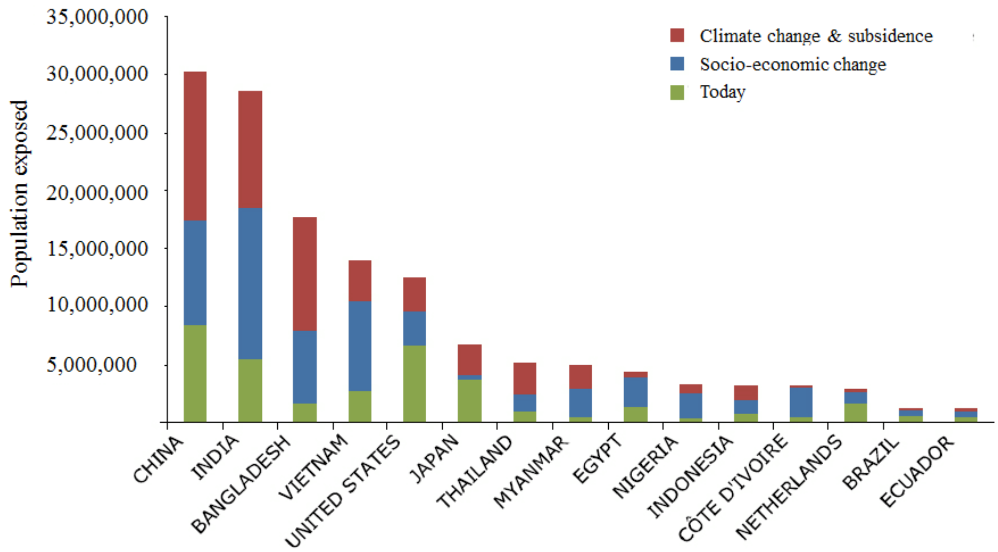

Figure 3.2 Top 15 countries by population exposed today and in the 2070s, showing the influence of future climate change vs. socioeconomic change
Source: (Nicholls, Hanson et al. 2008)

3.1.4 Mitigation and adaptation strategy of urban design

The energy consumption and the associated carbon emissions within a city, and city's climate vulnerability are dependent on urban design. It can develop land-use plans that promote urban growth in resilient locations, encourage urban densification, mixed-use development, climate-friendly traffic modes, and green infrastructure. Finally, it can increase the energy efficiency of the urban built form and reduce climate vulnerability. There are four key strategies: compact urban form, mixed land use, transit oriented development (TOD), and green infrastructure.

Compact urban form – Promoting compact urban growth can efficiently lower a city's carbon emissions. There is a strong relationship revealed by many studies between urban density and traffic patterns, particularly in the level of automobile dependence and the effectiveness of public transport (Newman and Kenworthy 1989, Newman and Kenworthy 1999, Kenworthy 2006, Dalkmann and Brannigan 2007). For instance, in a linear regression analysis of correlation between urban density and automobile use, the value of R^2 is up to 0.8392, which means urban density explains 83.92% of the variance in automobile travel (Kenworthy 2006). As density increases, public services and facilities tend to be concentrated, which reduces the need to travel long distances, correspondingly promotes the use of non-motorized traffic instead of private motorized traffic. In addition, in a highly populated city, major activity centers are concentrated in order to provide adequate passenger flow for public transport to increase its effectiveness, thus directing a transit oriented development in the city. Moreover, compact development can reduce energy and carbon intensity of infrastructure operation (water supply, wastewater treatment, electricity supply, etc.), e.g. dense city can be connected with relatively shorter water pipe networks than sprawled city, therefore energy demand and related emissions for water pumping and pressure maintenance is decreased.

Compact urban form directs cities to adapt to climate change. It encourages land-use in a dense, mixed-use way in low climate risk areas, and prevents green fields (farmland/ forest land) on the urban periphery from excessive development, which will enhance resilience of a city, and protect the carbon sinks.

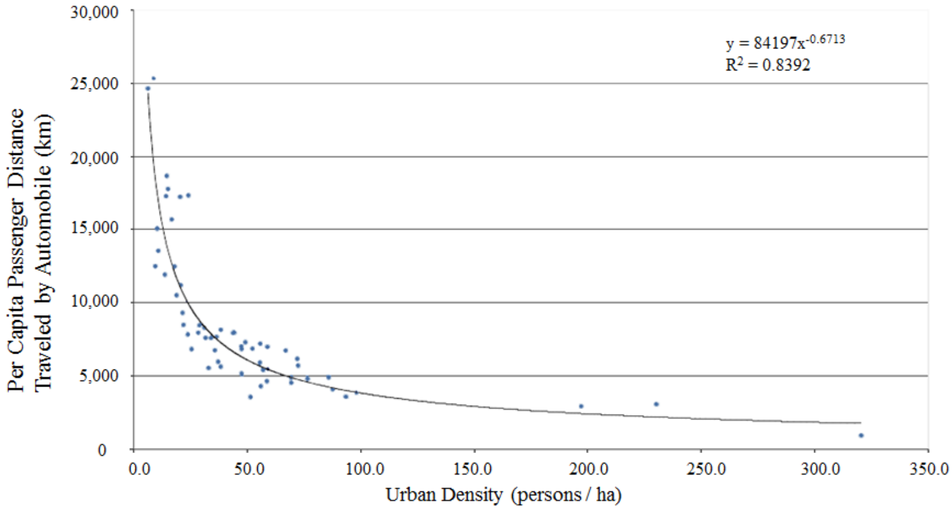

Figure 3.3 Urban density versus private car travel in 58 higher income cities (1995)
Source: (Kenworthy 2006)

Mixed land use – Mixed land use refers to the fact that the various forms of land use (such as residential houses, offices, shops, public services, etc.) are not separated in different city quarters, but mixed within close proximity of one another (Dalkmann and Brannigan 2007, Yokota, Hansen et al. 2012). As a complement of the compact development strategy, it decreases the distance and number of automobile trips, so as to reduce the associated energy consumption and carbon emissions. Smart mixed land use could reduce the demand for motorized mobility by keeping distances short. People are able to meet most of their daily needs by walking or cycling. Additionally, the mix of various functions enable people to link multiple tasks (commuting, shopping, visits etc.) into

Picture 3.1 Mixed-used Essen Hauptbahnhof

one trip, thereby reducing the number of trips. Empirical evidence demonstrates that the mixed land use could not only help the city to mitigate and adapt to climate change, but also enhance the quality of life it offers. An example that can be given is the mixed use development of the main train station in Essen (Essen Hauptbahnhof), including public transport, retail, catering, and public services. It improves the efficiency of travelers, and at the same time brings convenience to customers.

Transit oriented development (TOD) – TOD is a type of development strategy that coordinates public transport planning and land use planning in an integrated fashion to pursue mutually beneficial synergies. It promotes commercial and residential densification around transit stations that will encourage the use of public transport - a climate-friendly traffic mode (see 3.2), and provides people with conveniences (Wright 2005).

Transit oriented development, compact development, and mixed land use are a whole of mutual connection, promotion and organic unity (Petersen 2004, Wright 2005-3a, Yokota, Hansen et al. 2012). TOD can combine various forms of land use, such as housing, offices, schools and other key public services around a city's public transport system that guides its development concentrated along transit accessible lines and nodes, to avoid urban sprawl. On the other side, high density development at a transit connection point helps to improve the quality of access to public transport by reducing the average walking time to next the bus stop or rail station, while increasing the frequency of service. Mixed land use helps to ensure sufficient numbers of passengers use public transport throughout the day in every direction, by promoting multi-oriented travel demand distribution. For example, if the main residential area and work place are concentrated in different districts and orientations, tide traffic phenomenon will occur in the road between them. This results in a low load coefficient, operation efficiency and adaptability of public transport system.

As a result of Transit oriented development, cities will be led towards an ordered development. It significantly reduces the adaptation costs for infrastructure of all sectors. Besides that, TOD provides a well-constructed transit network that also plays a crucial role in disaster evacuation.

Green infrastructure – Green infrastructure is an interconnected network providing the "ingredients" for solving urban and climatic challenges by building with nature (Poetz and Bleuzé 2012). The aforementioned strategies of compact development, mixed land use and TOD can encourage dense and efficient urban development, but meanwhile it can intensify the heat island effect, exacerbate air pollution, and increase the risk of flooding. To avoid such "side effects", a dense city needs to be balanced by implementing green spaces to provide cooling, cleaning and infiltration. Green infrastructure offers great opportunities to mitigate and adapt to climate change, alleviate air pollution, and improve the quality of living environment to promote climatic, environmental and social multi-benefits in cities. In a report by Center for

Clean Air Policy (CCAP), these benefits were summed up as follows (Foster, Lowe et al. 2011):

> "Benefits include better management of storm-water runoff, lowered incidents of combined storm and sewer overflows (CSOs), water capture and conservation, flood prevention, storm-surge protection, defense against sea-level rise, accommodation of natural hazards (e.g., relocating out of floodplains), and reduced ambient temperatures and urban heat island (UHI) effects. The U.S. Environmental Protection Agency (EPA) has also identified green infrastructure as a contributor to improved human health and air quality, lower energy demand, reduced capital cost savings, increased carbon storage, additional wildlife habitat and recreational space, and even higher land-values of up to 30%."

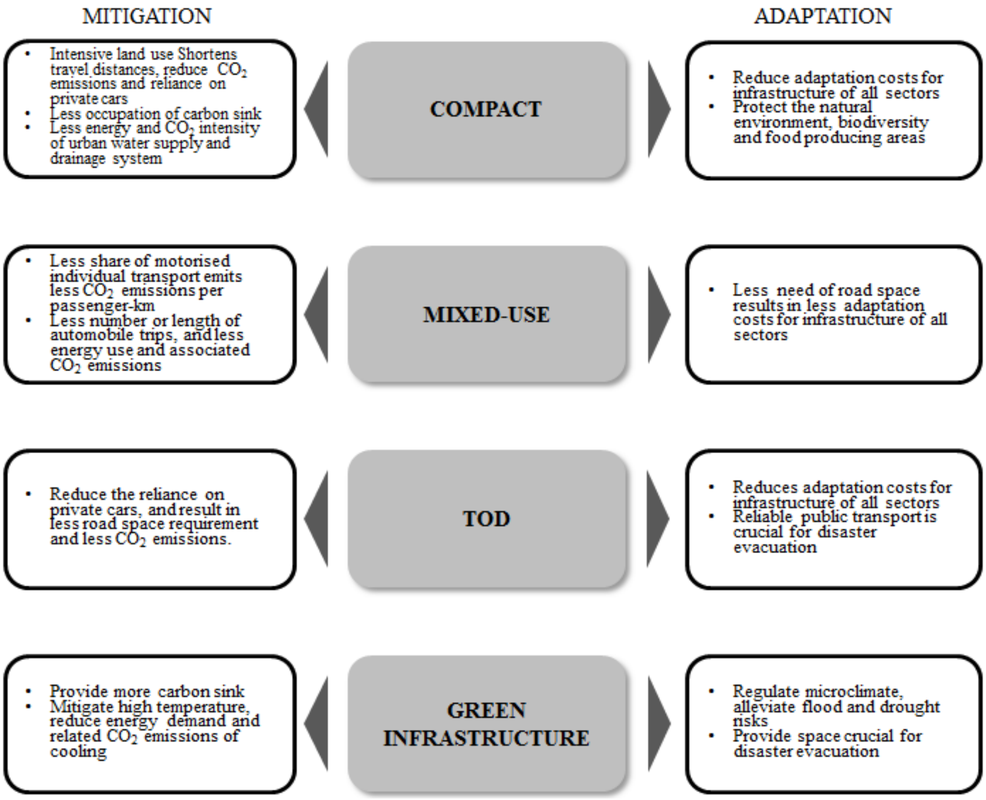

Figure 3.4 Climate change mitigation and adaptation of urban design

3.1.5 Urban design in low-carbon city evaluation

Site planning – Site planning is the critical first step of urban development, and has important implications for climate change mitigation and adaptation. While economic and related factors have favored the site of cities in certain environmental settings, the location and physical conditions of a city determine the city's vulnerability to climate change impacts. Careful site planning, which tries to avoid areas prone to climate and related hazards, can minimize climate risks to people and businesses and lower the adaptation costs. Furthermore, through deciding and enforcing where to promote city development, it also affects a city's land use intensity, trip distance and traffic mode that are strongly associated with the energy use and carbon emissions within the city.

Land use – "Land use refers to where and how people use land, for example, residential and commercial buildings, farmland, water supply, energy production, or forestry" (Word Bank, 2011). Land use planning is to balance the competing requirements of these functions on limited urban space, and further, the spatial distribution of the functions determines urban form that affects energy consumption and carbon emissions from many sectors, ranging from housing to transportation. A plan with appropriate urban population density, mixture of land uses and balanced job-housing can contribute to low carbon urban development. On one hand, it minimizes the distances between origins and destinations of urban trips, thus, helps to keep a high share of climate-friendly transport modes (i.e. public transport and non-motorized traffic). One the other hand, as described above, it helps to improve the energy efficiency of infrastructure and buildings.

Accessibility – Accessibility refers to people's ability to reach goods, services and activities, which is the ultimate goal of most transport activity (Litman 2008). As a measurement of the general cost (time, money, discomfort and risk) needed to reach destinations, accessibility determines the ease with which people can reach what they want (Litman 2011). Public transport is the key factor of green transportation system in cities, and at the same time, is a crucial way to improve accessibility. When the trip generation (housing) and trip attraction (work sites, shopping, services, etc.) are mainly clustered near public transport junctions, with high density and mixed land uses, the mobility and accessibility will be improved in the city, while the need for motorized individual traffic will be decreased.

Green open space – In general, urban open space is the land and water areas on all or most of which there is no artificial structure inside of city boundaries; more specifically, it means urban public green space (Zhang and Cen 2007). By way of good design, green open space could play a constructive role in regulating temperature, providing green shades and managing flood risks, thus, helping cities to mitigate the heat island effect and adapt to increased precipitation events. High-quality green spaces can reduce energy consumption for cooling purposes by lowering high temperature in summer days, and make non-motorized transport more attractive by maintaining a comfortable temperature for pedestrians and cyclists. Moreover, green space also serves as crucial carbon sink and emergency shelter within a city.

3.2 Transport

3.2.1Transport and climate change

Transport, particularly urban transport is interpreted to be one of the key and growing sources of greenhouse gas (GHG) emissions. It accounted for about 22% of energy-related carbon dioxide emissions globally (International Energy Agency-IEA 2012) and is the rapid rising sector of fossil fuels consumption and carbon dioxide emissions. According to the report by World Business Council for Sustainable Development (WBCSD) in 2004, a business-as-usual scenario could predict that the worldwide transport carbon dioxide emissions from vehicles will increase by 140% from 2000 to 2050, and the rate of growth in developing counties would be significant (Figure 3.5) (Fulton and Eads 2004). Another obvious example is the 27 European Union countries (Figure 3.6), during 1990 to 2011 GHG emissions from most sectors have decreased, i.e. industry (-32%), energy generation (-16%), household (-24%). Unlike these sectors, emissions from transport have increased significantly up to 28% (Randelhoff 2013). Moreover, transport is also one of the most difficult sectors in reducing carbon emissions since there are considerable small emission sources (i.e., vehicles), and it is closely related to the economic development.

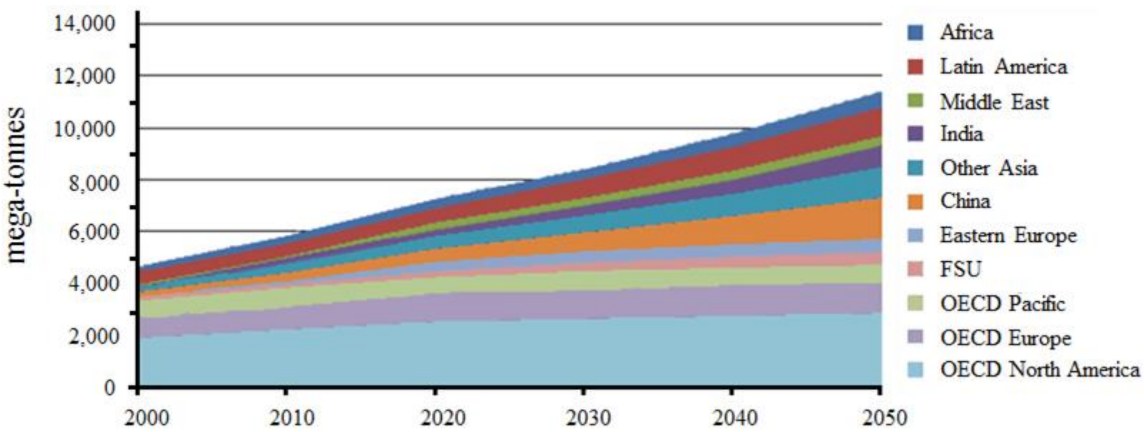

Figure 3.5 Transportation vehicle CO_2 emissions by regions
Source: (Fulton and Eads 2004)

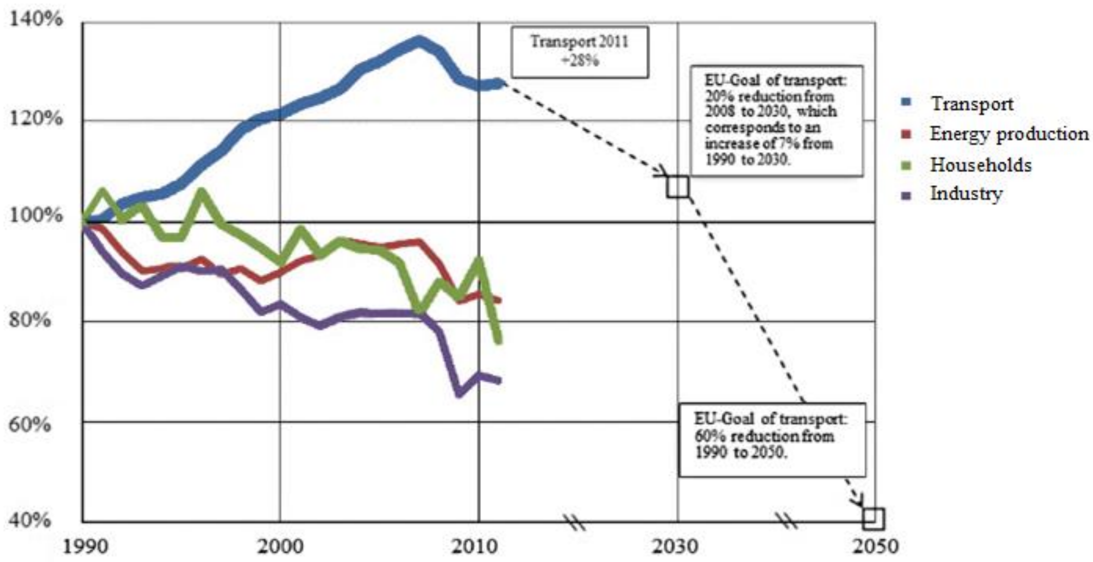

Figure 3.6 GHG emissions from sectors
Source: (Randelhoff 2013)

Due to the continuous urbanization and economic growth process, volumes and structures of urban transport change dramatically in China. Automobile has become the main source of CO_2 emissions and air pollution. After the promulgation of auto industrial policy was launched in 1994, the auto industry of China experienced a period of high-speed development. In 2000, every 100 households have only one car. However, by 2014, this number increased to 25 cars (Xinhua Net 2014). These changes are usually accompanied with increasing energy consumption and carbon dioxide emissions. Following a similar pattern of rapid growth, CO_2 emissions by transport in China grew to 160% from 1994 to 2007, and this growth is above the CO_2 emissions growth in all energy related activities (118%) in the country during the same period (Cai, Cao et al. 2011). According to statistics, in 2004, China's transport sector CO_2 emissions were approximately 290 million tons. This number is estimated to increase to 522 million tons in 2015 and 1.108 billion in 2030 (Ministry of Transport of the People's Republic of China 2008).

Besides contributing to climate change, the increases of motor transport bring other challenges to cities such as overloading existing roads, congestion, increasing accident rates and various problems of pollution. Accordingly, urban transport professionals all around the world have mostly acquiesced that car-based urban transport is not a sustainable path, neither with respect to urban functions, nor to the climate change or environment.

3.2.2 Contribution of transport to climate change

The amount of CO_2 emissions (E) caused by urban transport[13] depends on a number of

[13] Considering the difference among every city with different transport conditions, this study focuses on road

drivers. The relation of them is illustrated in the identity below, and where *i* is the trip mode, *T* is the number of trips, *D* is the distance of the trips, *O* is the vehicle occupancy, VKT is vehicle kilometers traveled, and E/VKT is the vehicle efficiency.

$$\sum E_{(i)} = T_i * D_i * O_i * (E/VKT)i$$

(1) The carbon emissions from urban transport has been increasing as a result of travel demand growth that is directly related to the number of trips and travel distances.

The growth of population and personal income drive an increase of the average number of trips. With the urbanization progress and population increase over more than 30 years, the average number of trips increased inevitably in Chinese cities. During the same period, demand for urban services has grown rapidly with the income level growth of urban residents. Accordingly, people's travel purposes became more diverse and the trip rate – trips per capita per day grew. In the past years, the estimations of annual vehicle kilometers traveled (VKT) of cars in Chinese cities has been up to about 38600-43500 kilometers (Knörr and Dünnebeil 2008). A survey of transport systems and CO_2 emissions of 17 Chinese cities suggested that the number of overall trips in most cities increased significantly in the last three decades, irrespective of city size, wealth, or geographical environment (Darido, Torres-Montoya et al. 2009).

Over more than 15 years, China has experienced explosive urban growth spatially. The substantial revenue stream from converting farmland into urban land[14] created a strong incentive for the municipal leadership to develop urban land excessively at low densities. The urban sprawl finally leads to longer travel distances. For most city residents, motorized transit is the inevitable choice to access work, education, and other public services when such services are beyond the viable distance of walking or cycling. Thus, the need for motorized travel is likely increase.

(2) It is crucial to reduce emissions from urban transport by lowering the CO_2 emissions per passenger-km against the background of an increasing travel demand. Two factors have to be considered: the trip mode and the vehicle occupancy rate.

The specific carbon emissions for a certain transport performance (passenger·km) first depend on the chosen means of transport. Compared to the average car, public transport and non-motorized transport are relatively "low emission" trip modes (Table 3.1). Generally, the cities with higher modal share for these low-carbon transport means tend to have lower GHG emissions per passenger-km. In Table 3.2, the modal share for public transport and non-motorized transport means are presented, as well as the CO_2 per capita per year for different cities. With the developing motorized traffic and the shrinking non-motorized traffic, the CO_2 emissions per passenger·km soar in cities in

transport that had the highest share on energy consumption and CO_2 emissions in transport.

[14] Municipal governments acquire rural land designated at rural land prices, then change it to urban land with improving urban infrastructure, and transfer its land use right to developers for property development at higher rates.

China. For example, in Beijing, this parameter increased 4.5% in ten years, from 49g/per passenger·km in 1995 to 76g/per passenger·km in 2005 (Li 2011).

In addition, CO_2 emissions per passenger·km are directly related to the average occupation rates, i.e. the number of passengers actually using the vehicles. As vehicle ownership increases at high rates, the occupancy of private cars is declining in Chinese cities. During 2000 - 2007, the average vehicle occupancy per trip decreased from 1.56 persons to 1.26 persons (Darido, Torres-Montoya et al. 2009). It indicates an increase in sole occupant car use over the period.

Table 3.1 GHG emissions of selected transport systems

Mode of transport	Maximum capacity (passengers per vehicle)	GHG emissions in grams per vehicle-kilometer	GHG emission in grams per passenger-kilometer (for 100% occupation)
Passenger Car (gasoline)	5	191	38.0
Passenger Car (diesel)	5	161	32.0
Diesel Minibus	40	750	19.0
Metro Rail (single coach)	117	1415	12.4
Diesel Bus	105	1038	9.9
Diesel articulated Bus	167	1402	8.4
Diesel bi-articulated Bus	270	1848	6.8
Bicycle	2	0	0
Pedestrian	-	-	0

Source: (Dalkmann and Brannigan 2007)

Table 3.2 CO_2 emissions from passenger transport vs. modal split in selected cities

Cities	% of public transport, walking and cycling	CO_2 emissions (kg per capita per year)
Houston	5%	5690kg
Montreal	26%	1930kg
Madrid	49%	1050kg
London	50%	1050kg
Paris	54%	950kg
Berlin	61%	774kg
Tokyo	68%	818kg
Hong Kong	89%	378kg

Source: (Bongardt, Breithaupt et al. 2010)

(3) At the vehicle level, improving the vehicle energy efficiency, in the form of emission control technologies or alternative fuels technologies, is an effective way to reduce CO_2 emissions and dependence on fossil fuels.

With strict vehicle efficiency standards, it greatly reduces the energy consumption and emissions while the vehicle kilometers traveled (VKT) remains the same. In Figure 3.7, China has lowered the fuel consumption levels of new vehicles by implementing the national fuel-efficiency standards for cars, SUVs and minibuses in 2005 and 2008.

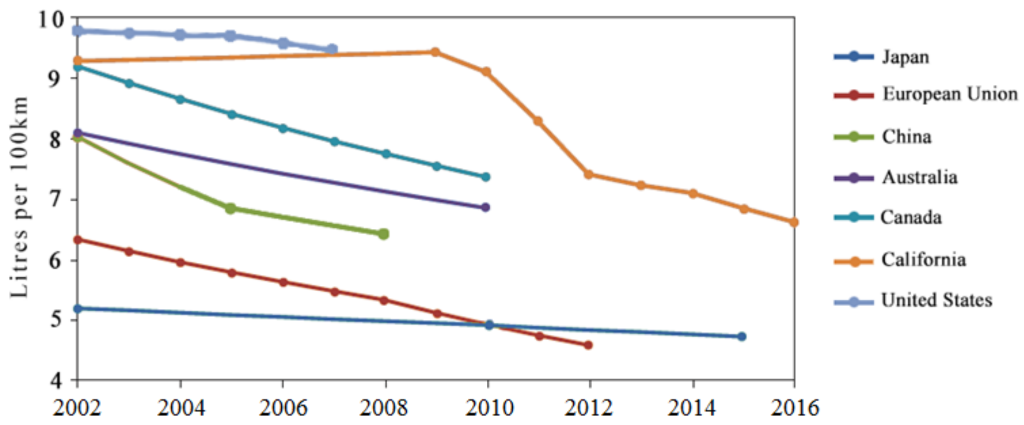

Figure 3.7 International comparison of average new vehicle fuel efficiency standards
Source: (International Energy Agency-IEA 2007)

In considering China's energy status quo and GHG emissions reduction targets, new energy vehicles[15] are expected to be an important element of low-carbon transport. The Rules on the Production Admission Administration of New Energy Automobiles was launched in 2007 by China National Development and Reform Commission. However, new energy vehicles could not be promoted widely in a short time, because of its high cost, low operation economy, and lack of supporting infrastructure. By 2012, it accounted for less than 0.1% of civilian vehicle ownership. It still has a long way to go to achieve the energy consumption and GHGs emissions reduction targets through advanced vehicle technologies.

Overall, the dramatic increase in travel demand and motorized trips in China are driving carbon dioxide emissions higher at unprecedented rates. It has almost fully overwhelmed the benefits of improved vehicle efficiency.

3.2.3 Impacts of climate change on transport

While transport impacts on climate, it is also affected by climate change. The most worrying of the expected impacts of climate change — increases in temperature and

[15] New energy vehicles are those vehicles which use unconventional vehicle fuels as a power source (or the use of conventional motor vehicle fuels but using new vehicle power unit), integrated with the power control and advanced drive technology, hence forming vehicles that have the advantage of advanced technical principles, new technology and new structure. NEVs can be divided into different types by kinds of fuels. There are hybrid electric vehicles (HEV), battery electric vehicles (BEV, including solar cars), fuel cell electric vehicles (FCEV), hydrogen engine vehicles, and other new energy sources (e.g. high energy storage devices, diethyl ether) vehicles of all kinds. Ministry of Industry and Information Technology (2009). Rules for New Energy Auto Manufacturing Companies and Products. M. o. I. a. I. Technology.

heat waves, droughts, sea level, intense rainfall events and storms intensity— pose enormous challenges to urban transport. In many cities of developing countries, the transport systems have been seriously impacted by extreme weather events, such as the huge floods in Beijing in July 2012 (Box 3.2).

The climate change impacts urban transport generally in three aspects: i) Infrastructure, it will need to be built and maintained to withstand worse weather, such as hotter weathers, intense rains and floods, and higher sea levels, etc.; ii) Vehicles, it will need to retain the function and comfort in more challenging weather conditions; iii) Mobility behavior, it will be largely influenced by extreme weather (Eichhorst 2009).

Box 3.2 July 2012 Beijing flood

The heaviest rain in 61 years hit Beijing on July 21, 2012. Within a day of the flooding, 56,933 people had been evacuated, while the floodwaters killed 79 people, causing at least US $1.6 billion economic damages. Beijing's transport systems were severely affected by the flood: many vehicles were trapped on seriously flooded roads; Airport Express closed; water poured into 9 subway lines.

Picture 3.2 Flooded street on July 21st 2012 in Beijing
Source: www.people.com.cn

Source: The author based on Wikipedia and various news reports in China.

3.2.4 Mitigation and adaptation strategy of transport

Effective response to climate change needs transport development strategies that fully consider both mitigation and adaptation to climate change. Hence, many countries, cities and organizations follow the coherent strategy "Reduce-Shift-Improve" (Picture 3.3) for a city looking to reduce transport emissions, which is very relevant to cities in China today.

Picture 3.3 Shift—Push—Pull effects
Source: (Rye 2010)

Reduce—reducing travel or the need to travel while maintaining mobility through integrated urban land use planning. As discussed in 3.1.2, the relationship between transportation and land use is interactive, and has a fundamental influence on the city's carbon emissions. Normally, land use planning that is oriented towards relatively high population density and mixed-use development, will reduce the travel demand (both the number of trips and their length) and the reliance on motorized private vehicles, while enabling better efficiency of infrastructure and public transport. Furthermore, transit oriented development (TOD) will also be a measure used to encourage higher density and diversity of urban functions by concentrating housing, offices, and key public services alongside cities' public transport corridors.

As a result of the "Reduce-oriented" urban land use planning, the travel for certain trips will not take place. In this case, CO_2 emissions for a trip that would previously have been made are reduced to zero. On the other hand, reducing transport demand through better land use planning, from the adaptation perspective, also means less exposure of infrastructure and travelers to climate risks.

Shift— promote a modal shift from the urban transport mode with high energy consumption and high emission towards more climate-friendly modes to satisfy the remaining transport needs. As described in 3.2.2, the different transport modes have different carbon emission intensities. Non-motorized transport (i.e. walking and cycling) represents the most climate-friendly option with zero GHG emission. Although public transport is not zero-emission mode, with a reasonable level of vehicle loading, its associated CO_2 emissions per passenger·kilometer are lower than private cars. Therefore, modal shift aims at strengthening non-motorized and public transport, as well as restricting the amount of travel on motorized individual mode.

By modal shift, trip efficiency of transport system can be improved, and accordingly results in lower energy consumption and carbon emissions per trip. In addition, the shift towards low-carbon transport modes can also help adapting to climate change. Public and non-motorized transport needs less space and built infrastructure compared to motorized individual transport (Picture 3.4). This reduces adaptation costs for roads. Moreover, public transport is the key instrument of disaster evacuation in a city, which becomes increasingly important with climate change.

Picture 3.4 Space requirements to transport the same number of passengers by different modes: car, bicycle, and bus

Note: It illustrates space requirements of 80 passengers either going by car, by bus or cycling.

Source: (Peterson 2004)

Improve—improve the efficiency of motorized transport through technological measures. As a complement to the above two fundamental strategies, the strategy "improve" pursues to reduce the CO_2 emissions of motorized vehicles (private cars and public transport vehicles) per unit of travel by improving vehicle and fuel efficiency and optimizing transport infrastructure. It includes measures of selecting lighter, more fuel-efficient vehicles; new types of engine technology; and lower carbon energy sources.

Advanced vehicle technology benefits not only in reducing carbon emissions, but also help the vehicles providing reliable and comfortable transit under changing climate conditions. It is indispensable, especially for public transport to maintain its attractiveness.

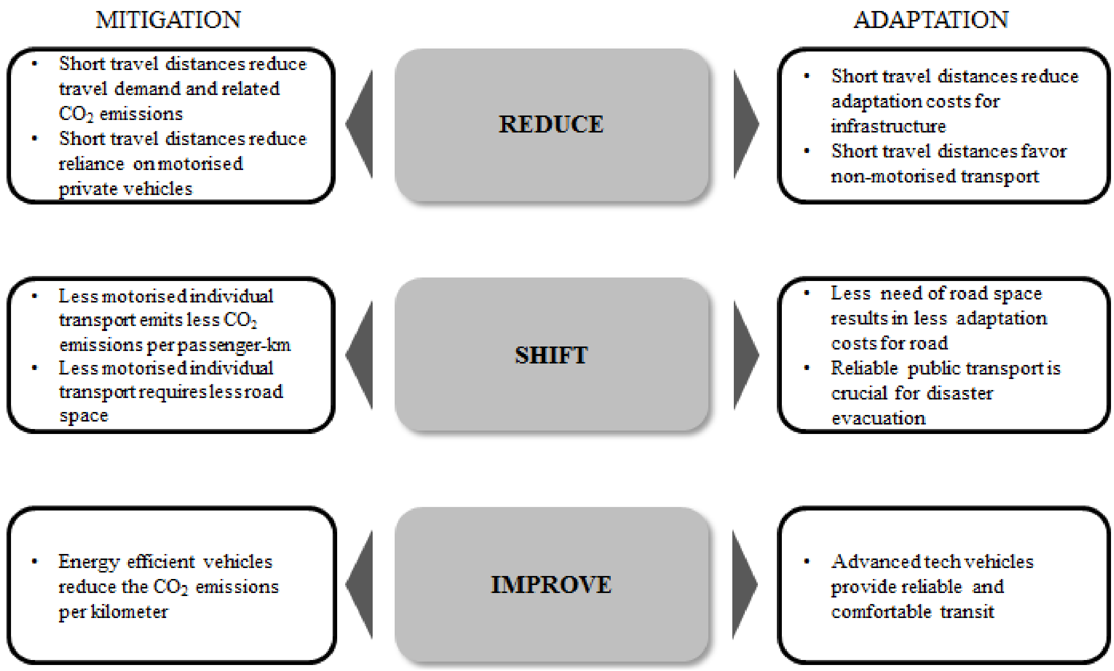

Figure 3.8 Reduce-Shift-Improve: mitigation and adaptation of transport system
Source: The author based on (Eichhorst 2009)

3.2.5 Transport in low-carbon city evaluation

Transport, as one of the significant sectors of low-carbon city evaluation, concerns four main aspects—motorized individual transport, non-motorized transport, public transport and freight transport.

Motorized individual transport: Private cars have undoubtedly the largest transport-related carbon emissions per capita in the urban transport system. Figure 3.9 illustrate that in Shanghai in 2005, private cars accounted for 30% of the total passenger performance, however, represented more than 50% of energy consumption and CO_2 emissions. Thereby, it is imperative that the development of motorized individual transport is restricted through Transport Demand Management (TDM) measures, such as parking management, road use management.

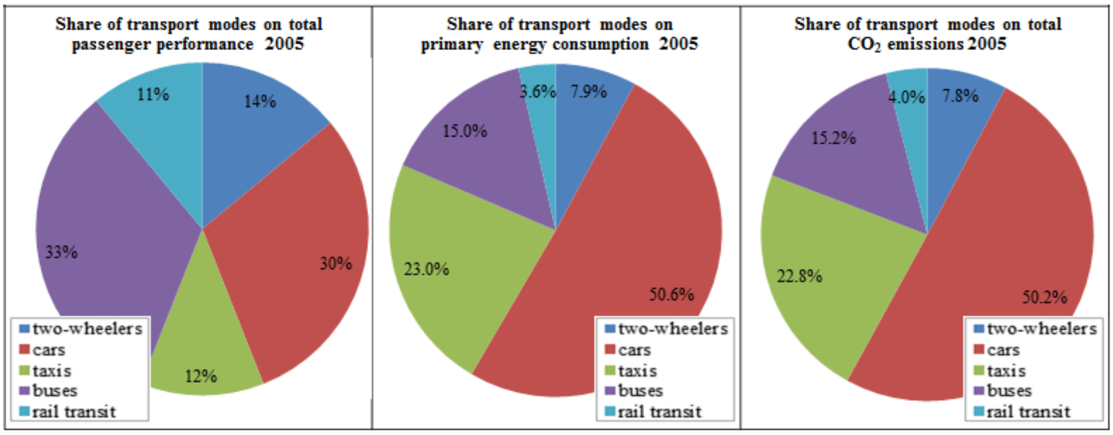

Figure 3.9 Share of transport modes on passenger performance, primary energy consumption and CO_2 emissions of motorized passenger transport in Shanghai in 2005
Source: (Knörr and Dünnebeil 2008)

Non-motorized transport: Walking and cycling are the essence of a low-carbon urban transport system, since they offer mobility without producing any GHGs and pollution. In the majority of Chinese cities, even though non-motorized transport remains one of the principal forms of mobility, its mode share fell in the last three decades. This was mainly because many cities adopted Car-Oriented-Development (COD) strategy, i.e. discouraging non-motorized trips through priority measures for automobiles. Many urban arterials in these cities are virtually impossible or fairly inconvenient to use by bicycle or other non-motorized modes. That forced massive potential non-motorized trips to rely on motorized modes. Under this condition, improvements need to be made to safety, accessibility and climate adaptability of pedestrian and cyclist infrastructure and facilities to ensure that they are attractive to existing and potential users.

Public transport: Efficient public transport will be a crucial element in any low-carbon urban transport strategy. As an alternative to motorized individual transport, public transport provides a variety of benefits: efficient space use, less infrastructure and facility requirement, low carbon emissions and low air pollution. In addition, it also undertakes the task of disaster evacuation.

China's rapid economic development poses serious challenges to urban public transport. The increasing income levels will enable an increasing number of commuters to acquire private cars if the public transport services are uncompetitive in comfort, reliability, speed, convenience, and cost. For promoting public transport, the key options are to expand the systems and improve the quality of infrastructure and service, in order to make public transit more attractive.

Freight transport: A functioning goods distribution and transport system is a major guarantee in maintaining the vitality and prosperity of urban economy. At the same time, it provides a significant source of carbon emissions, especially the road-based mode. In China, as a result of industrial structure change[16], freight traffic with trucks has been growing fast over the past ten years. In turn, trucks, as well as private cars, tend to be the other large contributor of CO_2 emissions. For achieving a low-carbon freight transport, such measures need to be considered: improving city logistic planning, promoting intermodality, and adopting advanced truck technologies.

In general, the objective of mobility evaluation is to guide the transport system of Chinese cities for a way of the low-carbon development while at the same time improving the welfare of individuals and increasing their mobility and accessibility, by taking such measures as restricting motorized individual transport, encouraging non-motorized and public transport, and improving freight transport.

3.3 Energy

3.3.1 Energy and climate change

Urban energy system is defined as "the combined processes of acquiring and using energy to satisfy the energy service demands of a given urban area" (Keirstead and Shah 2013). It is the "blood" of cities and key accelerator to economic vitality that supports the energy needs of households, businesses, transportation, health care, water management, and food systems (The World Bank 2011). As it is related to so many issues, the energy sector can be discussed in either broad or narrow terms. In broad terms, energy includes all kinds of energy consumption within a city. In narrow terms, the energy sector involves energy consumption for buildings in forms of electricity, heating, and cooling. In this section, analysis will focus on electricity and heat generation, as these are the bulk of energy used in most cities.

According to the report of International Energy Agency (IEA), the CO_2 emissions from energy systems worldwide experienced stable growth in the last decades (International Energy Agency-IEA 2012). Remarkably, the emission from the electricity and heat generation sector was the largest part, accounting for 38% of the total number in 2010 (Figure 3.10). Globally, fossil fuels such as coal/peat, oil and natural gas are the main sources to meet energy demand, and also the main contributor of those CO_2 emissions (Figure 3.11), and at the same time, excessive consumption of fossil fuels leads to serious environmental pollution and energy crisis.

[16] In China, industrial structure has been changing towards a setup with higher division of labor and higher degree of specialization. This leads to an additional demand for goods transportation linked purely to the industrial sector.

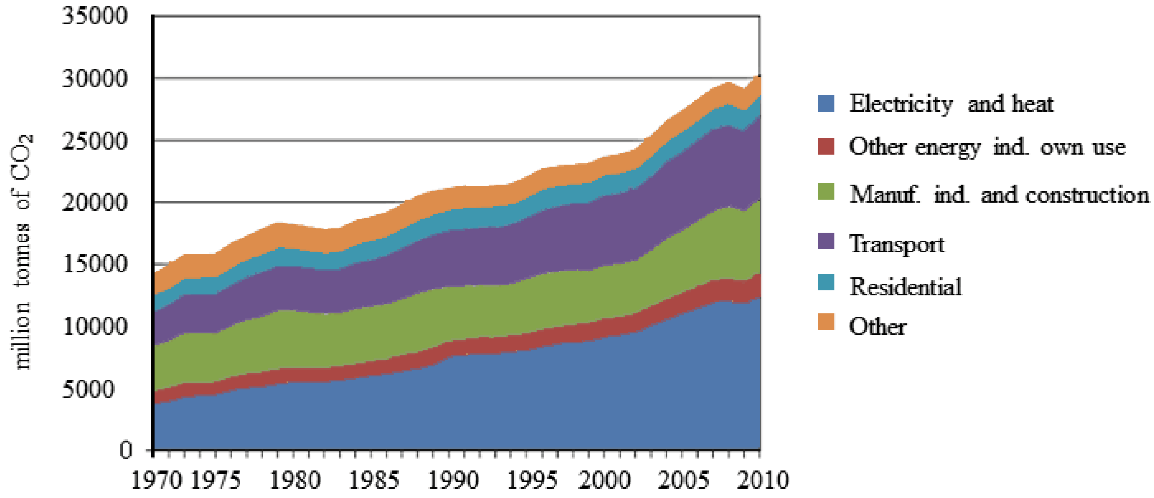

Figure 3.10 CO_2 emissions from different sectors from 1971 to 2010
Source: (International Energy Agency-IEA 2012)

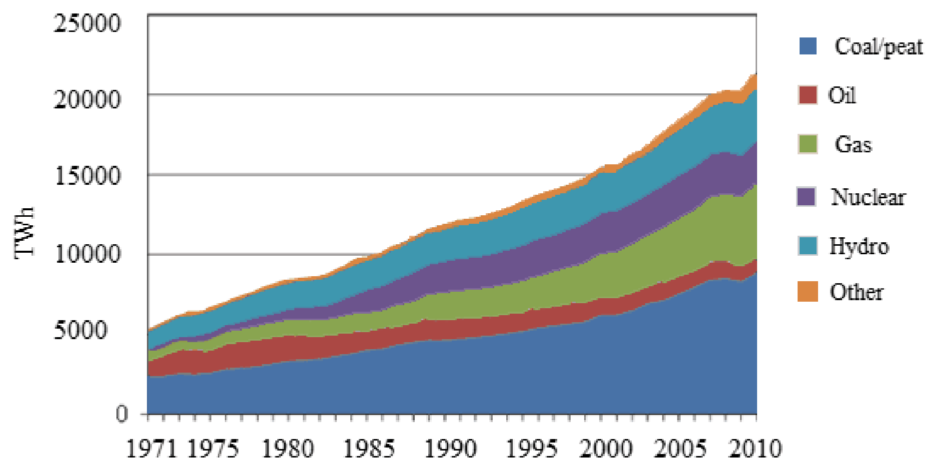

Figure 3.11 Electricity generated from fuel from 1971 to 2010
Source: (International Energy Agency-IEA 2012)

Along with the sustained and rapid economic growth, energy consumption in China is also soaring, characterized by high fossil fuel dependency. In 2006, China overtook the United States, becoming the world's largest emitter of CO_2. It is estimated that the total CO_2 emissions of China in 2013 were about 29% of the global CO_2 emissions of this year (Olivier, Janssens-Maenhout et al. 2014). Since 1990, emissions from the electricity and heat generation sectors have been increasing significantly, and till 2010 it took part of about 49% of the total carbon emissions (Figure 3.12). Although in the last twenty years, the overall efficiency of electricity generation[17] has been improved from 31.3% (392gce/kWh) in 1990 to 38.4% (320gce/kWh) in 2009 (Peng 2012), the gains had been overtaken by growth in aggregated demand (Figure 3.13). The heating

[17] Efficiency of electricity generation is evaluated by Lower Heating Value (LHV). LHV refers to a property of a fuel, defined as the amount of heat released by combusting a specified quantity (initially at 25°C or another reference state) and returning the temperature of the combustion products to 150°C.

sector is another major energy consumer. For example, in 2010 this sector consumed 152.5 million tons of raw coal, about 4.9% of total coal consumption in China (State Statistics Bureau of China 2012).

In addition to contributing to carbon emissions, high dependence on fossil fuels of the electricity and heat generation sector has resulted in energy crisis and unstable energy supplies, and environmental pollution. Especially smoke or other pollutants emitted seriously threaten the health of human beings (Box 3.3). Therefore, making effort to minimize the fossil fuels and carbon intensity in the electricity and heat generation sector is a crucial part of low-carbon and sustainable development strategies in China.

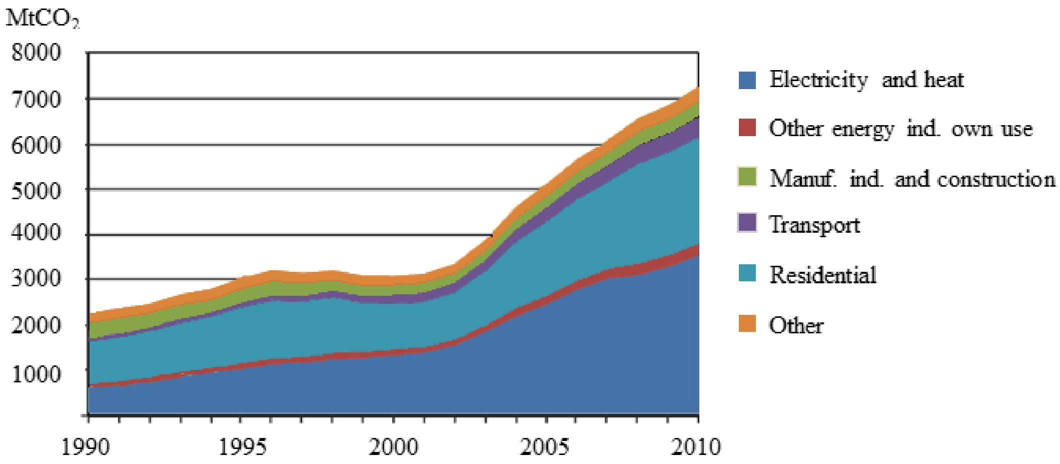

Figure 3.12 China: CO_2 emissions from different sectors from 1990 to 2010
Source: (International Energy Agency-IEA 2012)

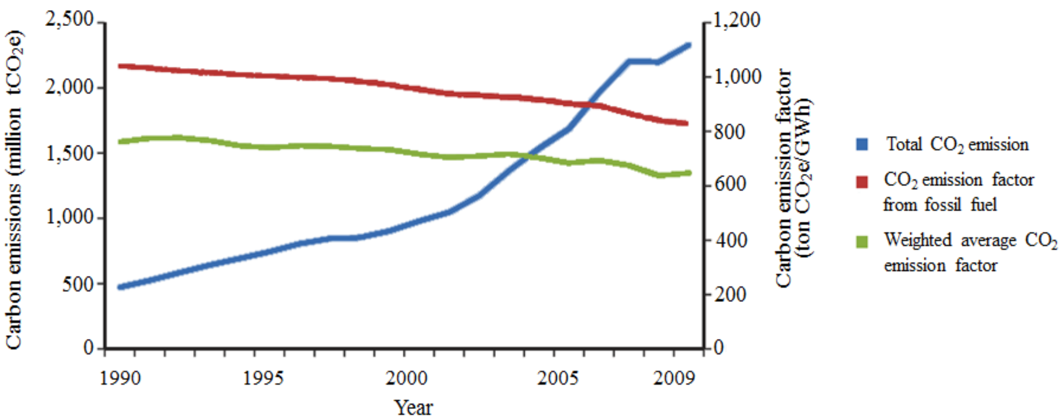

Figure 3.13 CO_2 emissions in the electricity generation sector from 1990 to 2009 in China
Source: (Peng 2012)

Box 3.3 Heating and average life expectancy – China

Recent study "evidence on the impact of sustained exposure to air pollution on life expectancy from China's Huai River policy" indicated that average life expectancies of the 500 million residents of Northern China are about 5.5 years lower than those in southern China, because of an increased incidence of cardiorespiratory mortality caused by air pollution from coal combustion. During 1950s to 1980s, the Chinese government adopted a heating policy that provided free winter heating via the provision of coal for the urban residents in north of Huai River, while the people who live in south of Huai River were not entitled to the free coal. The study suggested that this 30-year-long arbitrary policy resulted in serious air pollution in North China, thus, increased mortality caused by diseases related to air quality.

Source: (Chen, Ebenstein et al. 2013)

3.3.2 Contribution of energy to climate change

As described above, the electricity and heat generation sector is the main carbon contributor in cities, thereby attracts the most attention in urban carbon emission reduction. This sector can be analyzed in terms of supply-side and demand-side.

The supply-side consists of electricity and thermal energy supply and distribution systems. i) Currently, coal is still the dominant fuel for electricity and heat generation. Therefore, the combustion efficiency and carbon emission level of coal-fired power/heat plant largely determines the electricity and heat generation sector's overall efficiency and climatic impacts. Additionally, the proportion of renewable or cleaner energy in the energy resource structure of electricity and heat generation is another key factor determining the carbon intensity of this sector. Widely alternative use of renewable or cleaner energy instead of coal provides tremendous potential for carbon emission reduction. Figure 3.14 and Figure 3.15 shows the renewable electricity generation capacity and carbon intensity of power generation in Germany from 1990 to 2012, respectively. It is obvious that the CO_2 emissions pro kWh decreased significantly, when the use of renewable electricity increased. ii) Energy loss during power/heat distribution through power lines/heating pipes is inevitable, and results in efficiency loss of the electricity and heat generation sector. Optimization of electricity and heating distribution system can help to reduce the transmission losses, and improve energy efficiency.

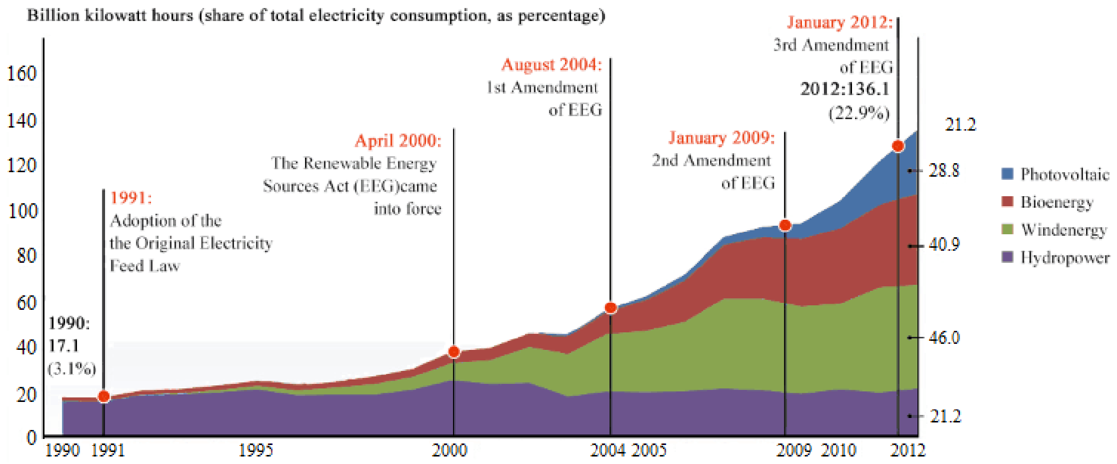

Figure 3.14 Electricity from renewable sources in Germany 1990-2012
Source: (www.unendlich-viel-energie.de 2013)

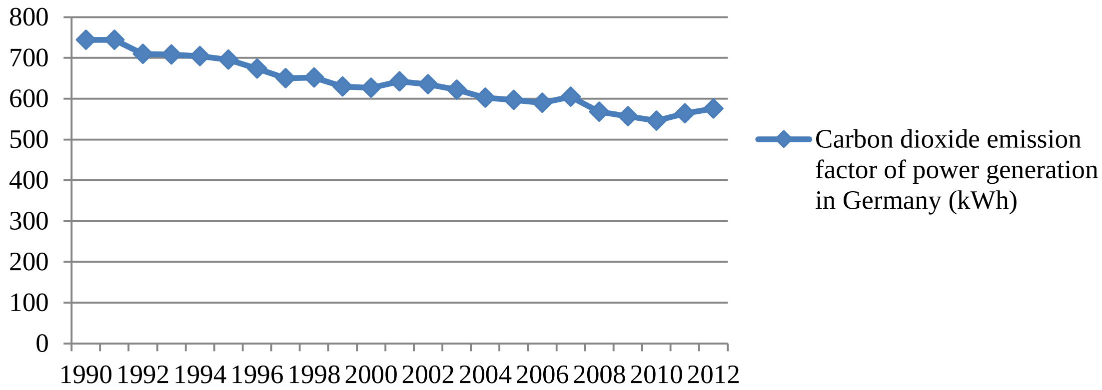

Figure 3.15 CO_2 emission factor of power generation in Germany 1990-2012
Source: (de.statista.com 2013)

The primary units of the demand-side analysis are power/heating demand and low-carbon energy use. i) Worldwide, sustained economic development drives growth in demand of power and heating in most cities, and the climate changes may serve as a catalyst in this process (Hammer, Keirstead et al. 2011). Though Electricity and thermal energy are clean emission-free secondary energy, their production processes produce a large amount of carbon emissions. Therefore, ineffective control of power and heating demand will impede low-carbon city development. ii) Promoting the purchasing and use of low-carbon energy can help to lower the carbon emissions associated with electricity/heat consumption in a city. For this purpose, the power system and government should take measures to provide an end user with a choice of low-carbon energy supply. For example, the "green electricity" programs[18] implemented in many countries, such as Germany, Netherlands, USA, Australia, etc. (Peng 2012). It gives end users the option to purchase and consume "green electricity" with a higher price,

[18] Under green electricity programs, utilities purchase or generate renewable-sourced electricity, and offer it as a distinct product to users. The end users have the option to purchase and use part or all of their electricity from the green sources.

with a guarantee that all the payment will be used in renewable energy production.

3.3.3 Impacts of climate change on energy

Many cities are currently reliant to a large extent on energy sources and system assets outside of the city, which makes the climate change-related impacts on energy supply and demand in urban areas more complicated. The following information is primarily based on from the report of Hammer et al. for the Urban Climate Change Research Network (UCCRN) (Hammer, Keirstead et al. 2011), unless otherwise noted.

Climate change may affect the **urban energy demand** through the impact of extreme heat – a virtually certain change of climate change is global warming. In urban areas, wide use of impervious surfaces, large amount of artificial heat sources from buildings, vehicles, and industry, and high level GHGs emission result in “urban heat island” effect – a phenomena whereby the temperature of the urban area is significantly higher than that of its surroundings. It can increase energy demand on space cooling on summer days (Santamouris and Georgakis 2003). Global warming may intensify heat island effect in cities and the pressure on local energy supply. This increases the risks of blackouts and brownouts. Lack of electricity and cooling systems affects industrial production and daily life in cities seriously, and poses health risks for people in burning hot summer (Klinenberg 2002).

Climate change could affect **urban energy supply** through impacts on primary energy fuel supply, energy production operation, and energy transmission and distribution. The climate risks of a city’s energy supply chain and severity of each risk varies by location.

Climate change impacts of rising temperatures, precipitation distributing variety, sea levels rising, extreme weather events, and associated secondary disasters may affect availability of primary energy fuel or the transport of fuels to the energy production sectors. For example, the offshore oil and gas drilling platforms and refineries are vulnerable to storm surges and extreme weather events. Once damage occurs, it will cause shortage of fuels and, thus, increased fuel prices. Besides, changing temperature and precipitation levels may reduce crop yield, thereby, affecting the availability of biofuels for biomass power generation. Inundation, storm, and other associated disasters can also affect the transportation infrastructure used for primary energy fuels transport, and lead to unreliable energy supply. For instance, the snow disaster in south-eastern and central China in 2008 caused delays in transport of fuel in many regions. As a result, 17 provinces were forced to ration power.

The impacts of climate change vary from different types of energy production and operations in cities.

- Thermoelectric and nuclear power plants need large quantities of water to cool them down. Warmer air temperatures may warm up the water, thus, cannot satisfy the cooling function. In addition, owing to the heavy need for water, many thermal and nuclear power plants were sited along waterways, and therefore vulnerable to flooding, rising sea levels and extreme weather events.

· Changing climate patterns may also cause hydrological change. This will affect the timing, level and type of precipitation available to feed hydropower plants.

· Biomass power generation is also vulnerable to climate variables because the availability of biofuels is largely depending on the factors such as air temperature and precipitation.

· Solar power generation is estimated to be affected by cloud cover increases (Pan, Segal et al. 2004). Wind energy generation is vulnerable to pattern shifts in wind speed, duration and directions. The impacts of climate change on these areas are still unclear and being studied.

Furthermore, climate change shows influence on energy transmission and distribution. As discussed above, the rising temperature level may push up urban energy demand in summer. At the same time, power demand burden over the rating level of transmission and distribution lines and electrical transformers will also be increased, which will damage the equipment and may cause outages. Moreover, energy transmission and distribution may also be vulnerable to storms and extreme weather events. As we witnessed in 2012, Hurricane Sandy caused large-scale outages in the United States, electricity networks of 15 U. S. states and the District of Columbia were affected to different extents. As of October 31, the worst affected states were New Jersey – 2,040,195 customers without power; New York with 1,933,147; Pennsylvania with 852,458; and Connecticut with 486,927 (U. S. Department of Energy Office of Electricity Delivery & Energy Reliability 2012). Owing to extensive wind and water damage, several facilities of energy generation, transmission and distribution remained closed for a long time after the storms passed. Until January 2013, there were still 8,200 people without power (Nessen 2013).

3.3.4 Mitigation and adaptation strategy of energy

Mitigation and adaptation efforts by the energy sector can offer the city numerous co-benefits, including reducing carbon emissions, increasing climate resilience, lowering risks of energy crisis, and ensuring local economic development. Based on the status of the energy system in Chinese cities, such efforts can be made in the following ways: optimize energy structure and control energy demand.

Energy structure optimization – Currently, cities in China have limited capacity to affect the national policies and measures relating to energy supply. In this case, energy structure optimization, which means increasing the share of renewable energy, new energy and clean energy in the energy structure, becomes a practical option to reduce their carbon emissions and enhance their climate resilience. On one hand, because the consumption of fossil energy is the main source of CO_2 emissions, to increase the share of non-fossil fuels in energy structure could efficiently decrease carbon emissions from the energy system. On the other hand, climate change may affect urban energy systems in many different ways, and the extent of impact will vary significantly according to the dependency of the system on a specific energy source. Hence, the diversified energy structure could weaken the dependence on one certain energy source, so the energy system can be safer and more climate-resilient.

Energy demand control – From 2000 to 2010, global energy demand has increased by about 1/3. It is notable that China accounted for nearly half of this growth (van der Hoeven 2014). Thereby, reasonable control of energy demand by improving energy efficiency and encouraging utilization of low carbon-intensity energy (e.g. renewable energy) is an indispensable strategy. To reduce the energy demand could make low-carbon energy alternatives more affordable (Draugelis and Li 2012). To be specific, when consumers use less energy, they can afford higher prices, but more low-carbon alternatives. Furthermore, energy demand reduction could lower the maximum power load of the energy system, so as to decrease its vulnerability.

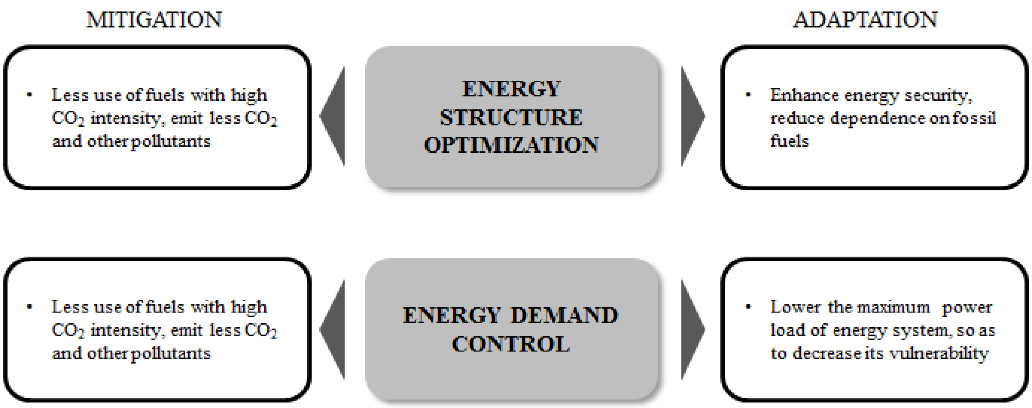

Figure 3.16 Mitigation and adaptation of energy

3.3.5 Energy in low-carbon city evaluation

The sector of energy is evaluated from two aspects: energy supply side and energy demand side.

Energy supply side – Energy supply of a low-carbon energy system should be diversified by increasing the share of low-carbon energy, such as solar, wind, and biomass, in order to reduce its carbon intensity, and additionally raise energy security by decreasing the dependence on fossil energy.

Energy demand side – For the purpose of developing low-carbon energy systems, efforts of energy demand side should be focused on energy saving and improving energy use efficiency, so as to tame rapidly rising energy demand and associated CO_2 emissions. Moreover, carbon emissions of energy demand side could be reduced also by introducing market mechanism and creating incentive policies that expand the use of low-carbon energy and control the demand of fossil energy.

3.4 Building

3.4.1 Building and climate change

The sector of building accounts for a large share of the worldwide energy consumption and GHG emissions. As the United Nations Environment Programme (UNEP) estimated, buildings are responsible for 30% of the world's annual GHG emissions and consumes up to 40% of all energy (United Nations Environment Programme - Sustainable Buildings & Climate Initiative 2009). According to the Global Building Performance Network (GBPN), with a hypothetical no-action scenario, buildings related energy consumption will increase by 110% in 2050 as compared to the amount in 2005 (Figure 3.17). Remarkably, such increases would happen almost totally in developing countries (Figure 3.18), as the construction activities are intensified by population growth, urbanization and economic development in transitional countries.

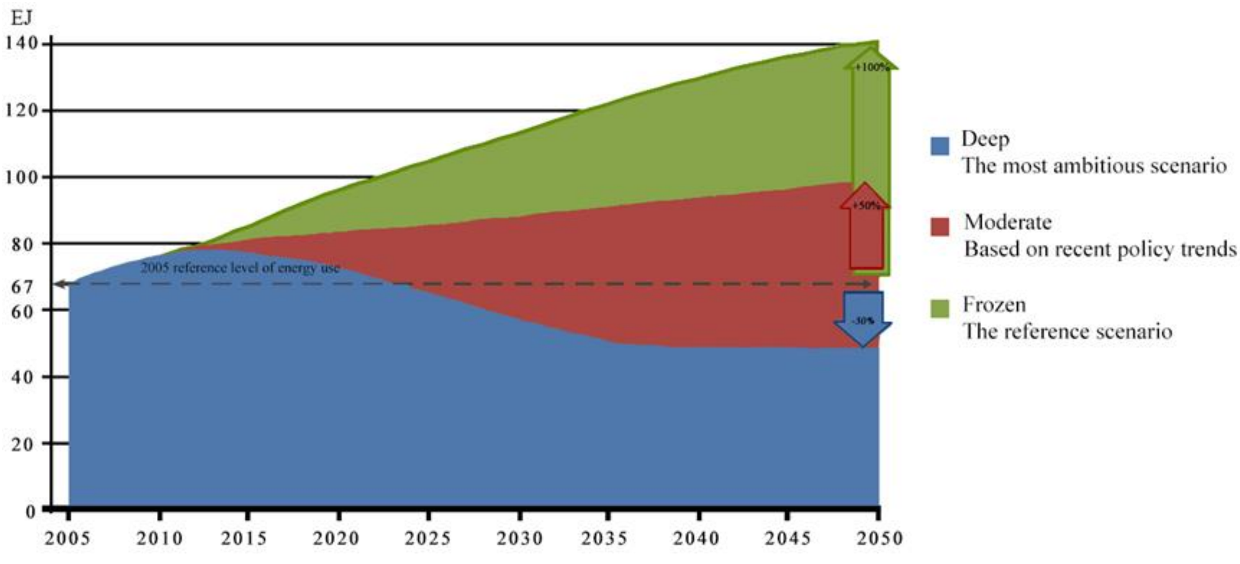

Figure 3.17 World total final building energy use for three scenarios

Note: Frozen Efficiency Scenario illustrates the development of energy use with no new policy or market developments since 2005. Moderate Efficiency Scenario illustrates the development of energy use under today's policy trends and ambitions. Deep Efficiency Scenario illustrates the development of energy use incorporating today's state-of-the-art know-how and technologies.

Source: (Global Building Performance Network-GBPN 2013)

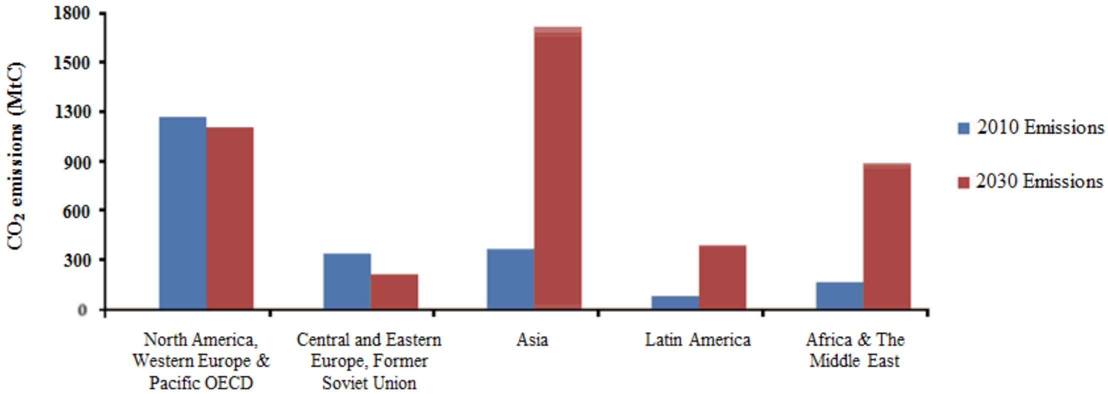

Figure 3.18 Current and projected building sector emissions by world region
Source: (The GLOBE Alliance 2012)

China, a developing country, is just experiencing a high-speed urbanization period. The incessant development and expansion of cities drives a dramatically growing demand for housing, commercial office space, and other building types (Figure 3.19). Thus far, it has become the biggest real estate market in the world, with every year up to 2 billion square meters new constructions. This number represents half of the annual construction quantities globally. More noteworthy is that over 80% of these new buildings would be high energy consuming buildings, while the ratio is even higher in existing building stocks at more than 95% (Xinhua Net 2015). The building sector is one of the largest energy consumers and carbon emitters. According to statistics, the building sector in China takes 25-28% of the country's total energy consumption, and contributes approximately 40% of the CO_2 emissions. If buildings are to be operated pursuant to current standards continually, the related problem of energy shortage and carbon emission will be strongly exacerbated by the urban demographic pressure. The former vice minister of China's Housing and Urban-Rural Development Dr. Qiu Baoxing has pointed out "Constructions consume a huge amount of resources and causes serious pollution while providing benefits to us. Now we are approaching a dangerous tipping point where we will exceed the ecological capacity."

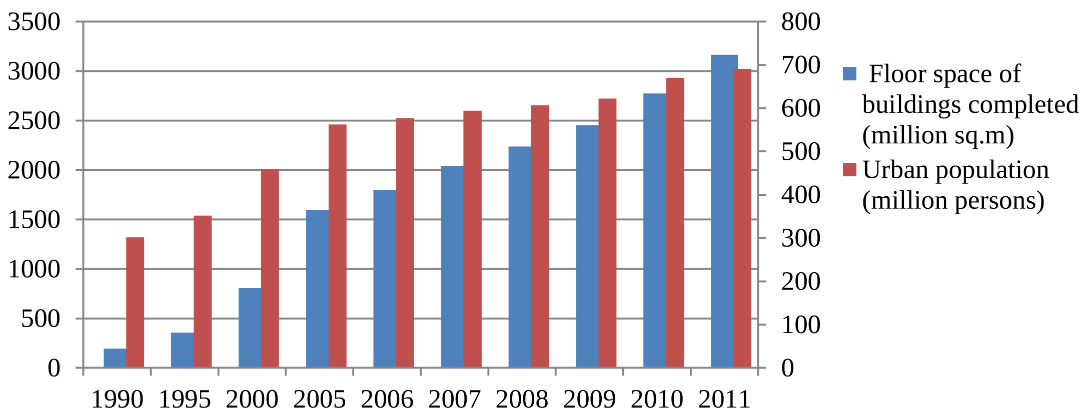

Figure 3.19 Development of urban population and floor space of building in China
Source: (State Statistics Bureau of China 1990-2012)

Box 3.4 Urbanization worldwide and China

A study of United Nations, Department of Economic and Social Affairs (2011) has shown that 52.1% of the global population (3.63 billion) was resided in cities in 2011, while by 2050 this number is projected to increase to 67.2% (6.25 billion). That means an additional 2.62 billion population will move to cities. In less developed regions, the percentage of population residing in urban areas will also increase from 46.5% in 2011 to 64.1% in 2050. Its 24.5 billion urban population growth accounts for more than 90% of the growth worldwide. As a high-speed urbanized country, 77.3% of China's population (1 billion) is expected to live in cities in 2050, compared 50.6% in 2011.

Source: (Heilig 2012)

From another point of view, the building sector meanwhile has immense potential to become more energy efficient, low-carbon and climate resilient. In GBPN's 2013 report, it has projected that with today's state-of-the-art know-how and technologies, energy use in buildings in 2050 could be reduced by 10% of that of 2005 and CO_2 emissions could be reduced by 12% in China (Global Building Performance Network-GBPN 2013). Additionally, since buildings are generally long-lived, their performance has a long-term effect on a country's energy efficiency and carbon emission. As stated above, buildings are seen by climate change experts as a key area of realizing low-carbon city.

3.4.2 Contribution of buildings to climate change

Buildings consume energy and emit carbon dioxide in a number of ways. The definition of energy consumption and CO_2 emissions from the building sector has narrow and broad perspectives. From the narrow sense, it involves only the building operational energy and carbon emissions that are due to heating, cooling, lighting, ventilation and other appliances. The broad sense, on the other hand, suggests considering a building's energy consumption and related emissions over the 'cradle to grave' aspects. In a building's whole lifespan, energy use and carbon emissions take place in five phases: production of building materials; transportation of building materials; construction of building; operation of building; demolition of building (Jones 1998). Since the phases of building materials transportation, construction and demolition accounts for a relatively small share of the total life cycle energy consumption and CO_2 emissions, emphasis is given to the phases of building operation and material production in this sector.

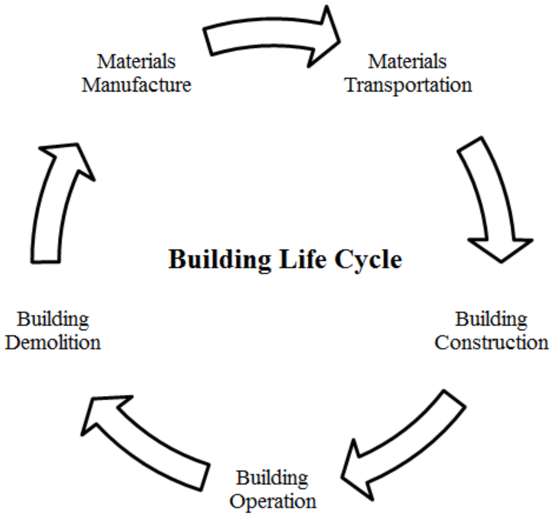

Figure 3.20 Life cycle phases of building

(1) The operational phase

The operational phase of building is the most energy- and carbon- intensive phase. Over the whole life cycle, more than 80% of GHG emissions occur during the operational phase of buildings. Energy is consumed for heating, cooling, ventilation, lighting and other applications (United Nations Environment Programme - Sustainable Buildings & Climate Initiative 2009). Buildings generally have a long period of use that over time it adds up to much more energy than is used for all other phases in its lifespan. As illustrated in Figure 3.21, in China, the total operational energy consumption of existing buildings has increased constantly from 1980 to 2009. Especially, after 2000, there was a high-speed growth stage along with the rapid urbanization development. In 2009, it accounted for up to 23.39% of total energy consumption. Thus, the operational energy is the key to improving building's energy efficiency and reducing CO_2 emissions that are of foremost concern.

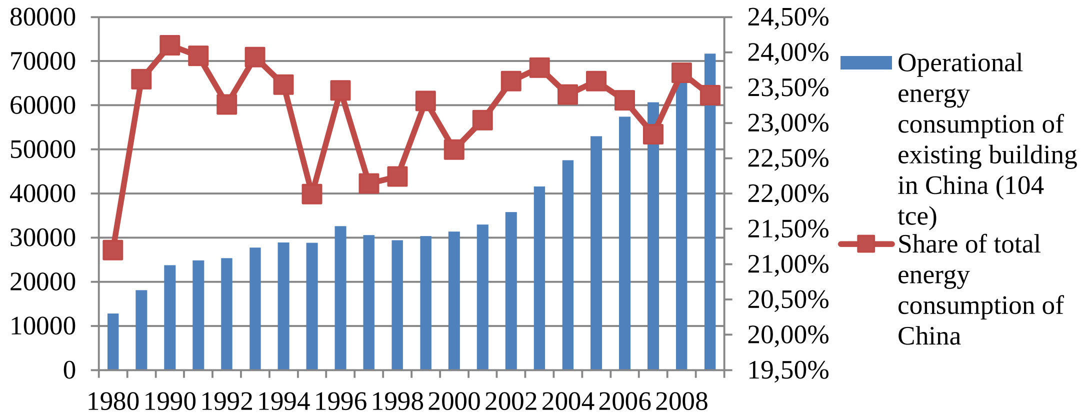

Figure 3.21 Operational energy consumption of existing buildings in China and share of total energy consumption 1980-2009

Source: (Cai 2011)

(2) Production of building materials

Following energy consumption of building's operational phase, the energy use, for the production of building materials is another essential part in the building life cycle. It corresponds to energy consumed by all processes associated with the production of building materials, such as steel, nonferrous metals, non-metallic materials and chemical materials, etc. Building constructions consume massive amounts of materials, especially energy-consuming and carbon-intensive products like steel and cement. Each year, China uses up to 40% of the world's demand for cement and steel for 2 billion square meters of new buildings. Building materials production is indisputably a big CO_2 emitter. Figure 3.22 shows the energy use of building material production and its share of total energy consumption during 1980 to 2009 in China. Along with the urbanization process, energy consumption used by building materials production continued a rapid growth. It accounted for approximately 14% of the total energy consumption. Therefore, besides the operational phase, the energy efficiency and CO_2 emissions of material production is significant.

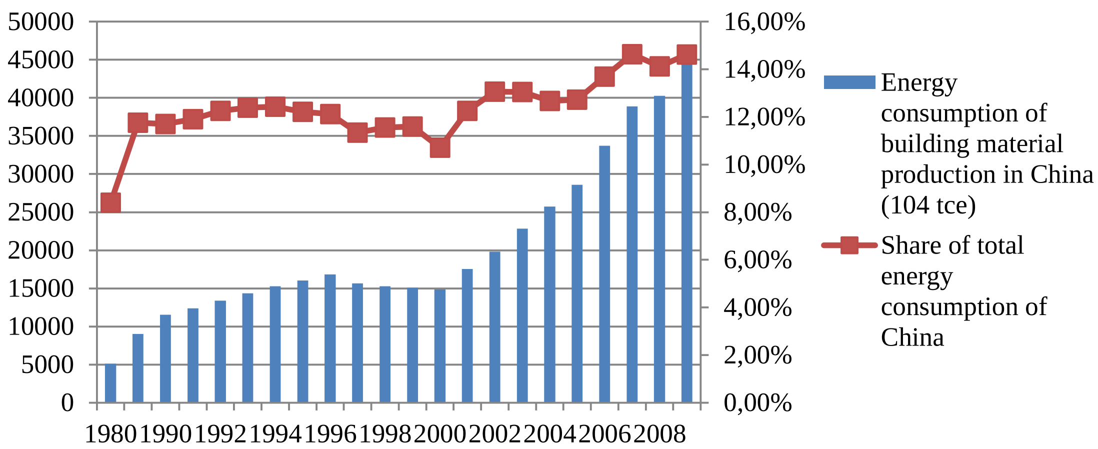

Figure 3.22 Energy consumption of building material production in China and share of total energy consumption 1980-2009

Source: (Cai 2011)

3.4.3 Impacts of climate change on buildings

Every aspect of our life will be affected by climate change, the buildings are no exception. Some of the greatest concerns are as follows:

- Windstorms, including tropical cyclones, which are predicted to have much greater intensity and frequency with climate change, will increasingly threaten cities' buildings. Because of their extreme nature, erosion and landslides could happen more frequently, which may cause significant damage to buildings and other structures.

- As a forecasted change in climate phenomena, more frequent heavy precipitation events will substantially increase the flood risk to the buildings located adjacent to rivers and deltas. This would be a serious challenge to the buildings' drainage capacity.

- Many regions of the world share the problem of rising sea levels, especially in such island nations and low-lying coastal countries. It will cause coastal flooding, and can be more acute when combined with storm surges, then severely impact buildings in coastal areas.

- Warmer weather resulting from climate change could have a direct impact on buildings' energy use and its composition. (Box 3.5)

Box 3.5 Average temperature and heating of building

Urumqi is a big city in north-west China with 3.1 million resident populations that is characterized by "cold in winter and hot in summer". In the last decades, the average temperature of this city has risen slightly (Figure 3.23). Recent research found that as the weather is getting warmer, the heating degree days (HDD) of Urumqi decreased (Figure 3.24), and on the contrary, the cooling degree days increased to some extent (Figure 3.25). It was proved that heating/cooling degree days are approximately linearly related to buildings' operational energy, then this result reveals the impact of global warming on buildings (Şen and Kadioglîu 1998).

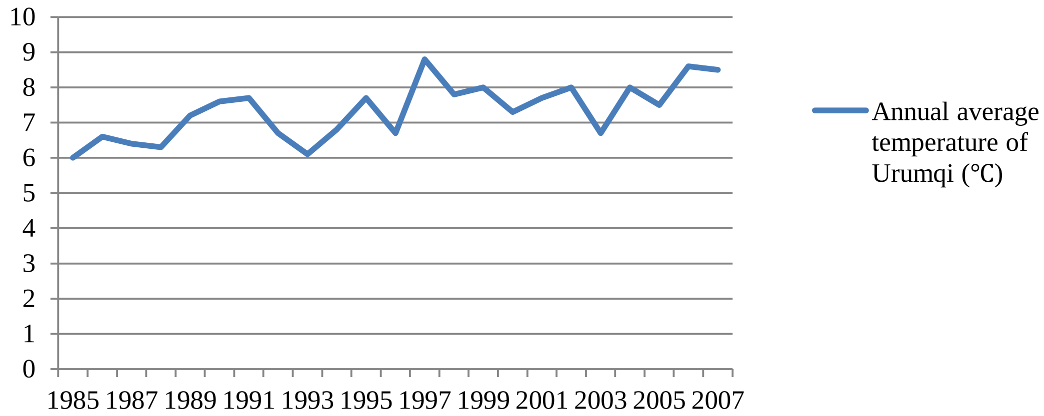

Figure 3.23 Annual average temperature of Urumqi 1985-2007
Source: (State Statistics Bureau of China 1986-2008)

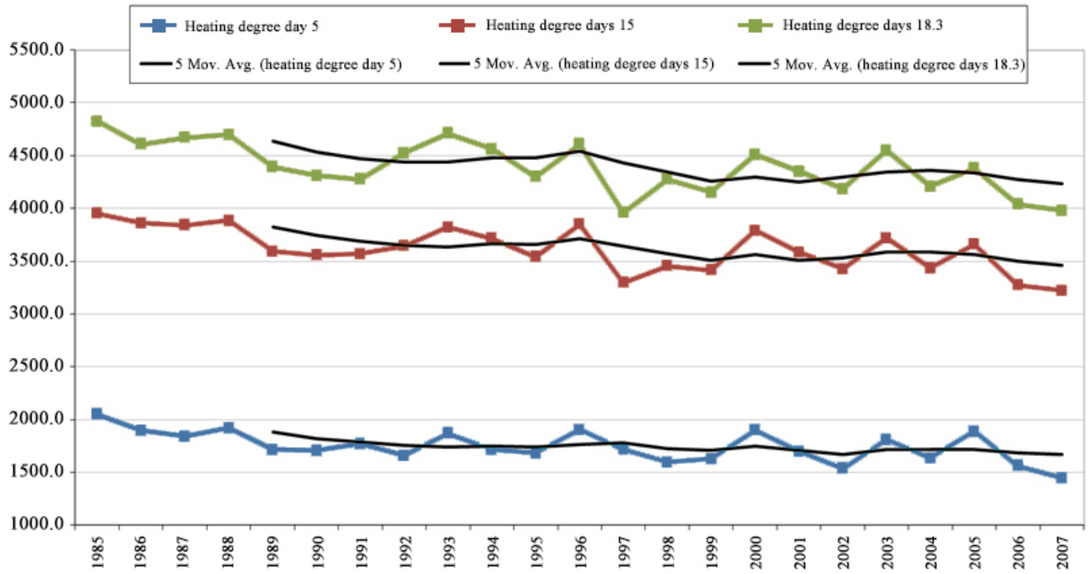

Figure 3.24 Heating degree days (HDD) of Urumqi 1985-2007
Source: (Chen 2016)

The lines in blue, red and green represent HDDs that have different base temperatures. The values on the black lines are the average values of HDDs of the recent five years.

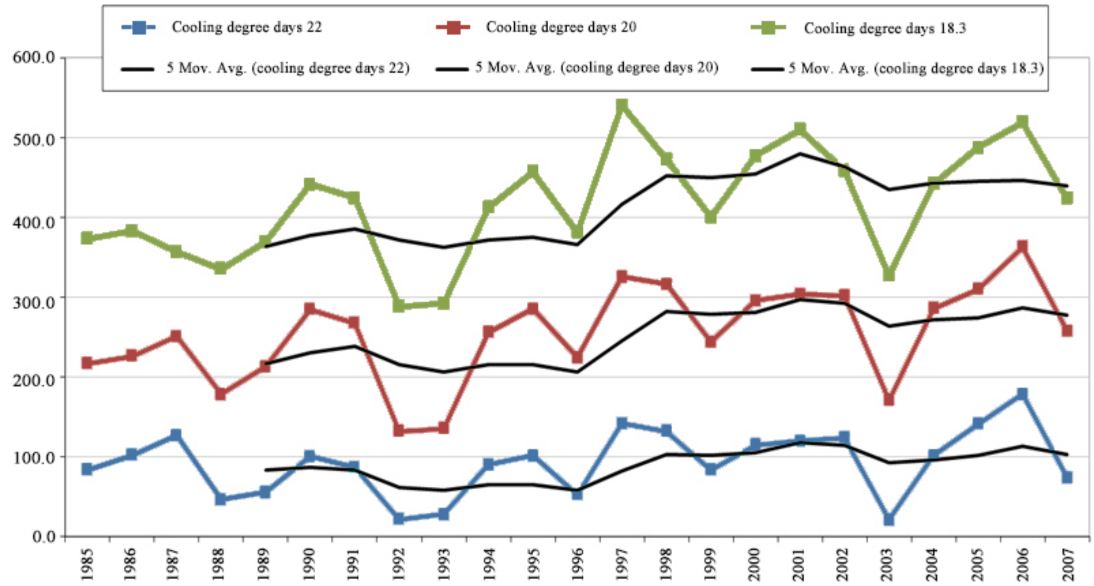

Figure 3.25 Cooling degree days (CDD) of Urumqi 1985-2007
Source: (Chen 2016)

The lines in blue, red and green represent CDDs that have different base temperatures. The values on the black lines are the average values of CDDs of the recent five years.

3.4.4 Mitigation and adaptation strategy of building

Facing both energy crisis and global warming, to make the building stocks become more energy efficient, low-carbon and resilient to climate change effects is the ultimate goal of many countries, including China. It could be achieved through these ways: i) energy efficient building design; ii) energy efficient building operation; iii) renewable energy utilization.

Energy efficient building design – The energy efficiency of a building is always related to two elements: how the building envelope is constructed, and how the building is designed in the local context.

By using efficient building envelope design, high quality insulation and sun protection in summer, the thermodynamic performance of the building's physical envelope can be improved, and in turn become more energy-efficient and low carbon. Building envelope contact directly with the exterior, it is the main part of heat transmission. For this reason, efficient envelope design with less exterior wall area can minimize energy losses. On the contrary, a more complex design may need an increased amount of exterior wall space, consequently, resulting in more consumption of building materials and larger energy losses. In addition, as key components of building operational energy, heating and cooling energy demand largely depends on the performance of building envelope insulation. According to UNEP, an envelope with high levels of insulation (incl. walls, roofs and windows) and good building airtightness is a passive way to obtain a low heat/cool demand and improved thermal comfort (Huovila 2007). Moreover, sun protection also plays an important role in reducing the energy consumption from the building sector. Well-designed sun shade, especially with green elements (e.g. green roof, tri-dimensional greenness) can reflect the majority of the sunlight in summer days and keep the associated heat away. This will significantly decrease the amount of energy needed for cooling.

Moreover, building's energy efficiency is not only determined by the building itself, but also affected to a large extent by the local environmental conditions, such as climate type, prevailing wind, urban form, etc. By taking them into account in building design, substantial energy demand and related carbon emissions can be reduced at very low or zero cost through the maximum utilization of natural daylight, natural ventilation, and passive heating/cooling. In China, for instance, south-oriented buildings are widely prevalent, which is a kind of design with nature. China is located in the Northern Hemisphere, north of the Tropic of Cancer, thus the sunlight comes only from the south. Based on that, buildings facing towards the south have many obvious advantages in accessing natural daylight and solar radiation than towards any other orientation. Furthermore, China is a typical monsoon climate country. In summer days, since the southerly wind dominates, south facing buildings have better ventilation to permit natural cooling. In winter, the prevailing wind will turn to northerly wind. Less exposure to the cold winter monsoon reduces heat loss, and accordingly benefits in maintaining the indoor thermal comfort level.

Energy efficient building design is not only beneficial to energy saving and CO_2 emissions reduction, but also important to climate change adaptation. A better insulated envelope can provide building with better interior thermal comfort, to adapt to the warmer circumstances and more acute heat waves, and ultimately retain the building's resilience.

Energy efficient building operation – The operational energy is generally the major part of the total energy used in buildings. It is mainly constituted by the energy consumption for heating, air-conditioning, ventilation and lighting. Therefore, improving the efficiency of HVAC (Heating, ventilation and air conditioning) systems and lighting is one of the effective measures of lowering energy use and CO_2 emission from the building sector. Among them, space heating and cooling is the main end-use in buildings. In developed countries, most residential energy is consumed for this purpose with 60% at an average level (Huovila 2007). This number is similar in China. To realize a more efficient heating and air-conditioning system, optimal design should be made on source, distribution net and end-use of the system. As essential appliance, ventilation and lighting are also driving the growth of energy consumption of buildings (International Energy Agency-IEA 2006). The energy performance of them can be improved by using, among other things: controlled ventilation, heat recovery of the exhaust air, efficient illuminants, fittings, and avoid over illuminating.

Since the impact of climate change on energy security is unknown, efficient energy systems in buildings, providing good indoor conditions with low energy consumption and CO_2 emissions, are significant in coping with energy crisis, and adapting to extreme weathers brought on by climate change.

Renewable energy Utilization – Besides the above mentioned optimizing solutions, adjusting the energy structure in buildings and promoting the use of renewable energy should also be considered by the dwellers. Compared with the traditional energy widely used in buildings, renewable energy resources, as solar, wind and hydro power, geothermal, bio-energy etc., have outstanding advantages of their huge resource potential and sustainability, and less environmental impacts. To fulfill the energy demand of buildings with this kind of energy can satisfy the indoor comfort of the dwellers, while minimizing CO_2 emissions. On the other hand, increasing the share of renewable energy in the energy consumption structure will effectively reduce the building's reliance on carbon-intensive fossil fuels. Thereby, it helps buildings to actively cope with the climate change and the energy crisis caused by excessive consumption of traditional energy.

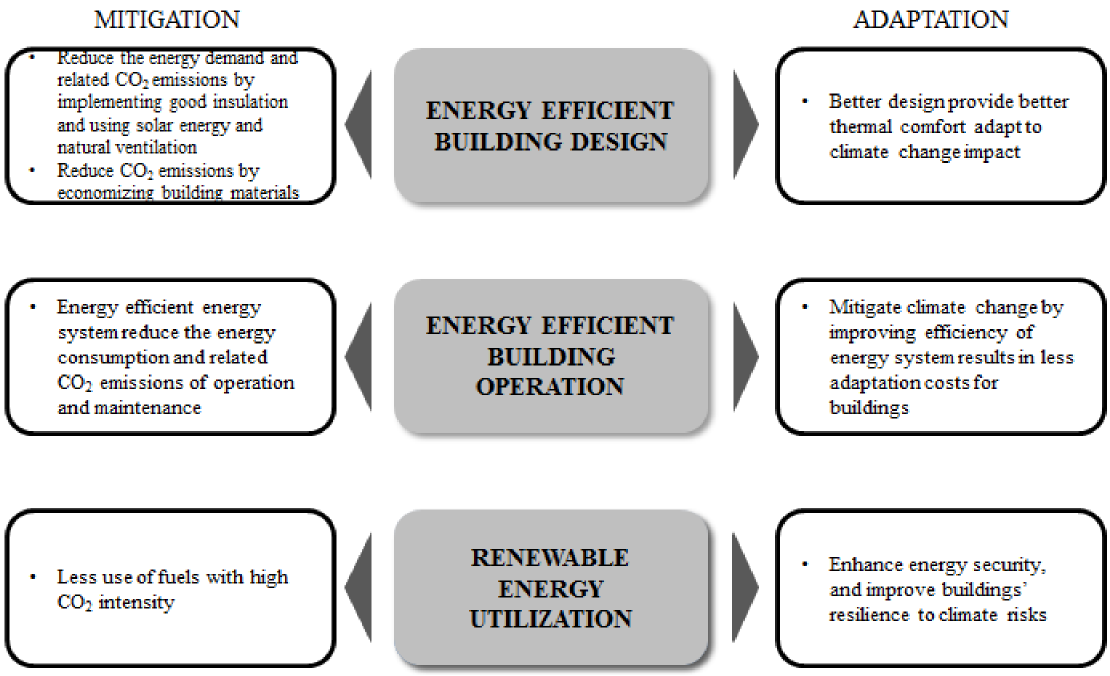

Figure 3.26 Climate change mitigation and adaptation of building

3.4.5 Building in low-carbon city evaluation

The key to achieving building energy efficiency and low carbon emission are: promoting energy conservation in new buildings, and encouraging the reconstruction of existing buildings.

New buildings – As mentioned above, half of the global construction from 2000 to 2020 happens in China. However, it is remarkable that 80% of these new buildings would be high energy consuming buildings. Adoption of energy-saving technologies and standards in new buildings could help improve building's energy efficiency, and in turn address this situation.

Existing buildings – According to the China Intelligent Building Industry Development Prospects and Investment Strategy Report (2013-2017), there are more than 50 billion square meters of existing building stocks in China, over 90% of the existing buildings are high energy consuming (Qianzhan Business Information Co. Ltd. Industry Research College 2014). Compared to new buildings, the energy-saving reconstruction work for existing buildings in China is larger and has more potential to lower the level of energy consumption and carbon emissions.

3.5 Water

3.5.1 Water and climate change

Water is the basic condition and essential resource for the existence and the development of cities. In human history, early cities grew up mostly along rivers. This illustrates the importance of water for urban survival, human fertility, and social civilization. Currently, growing population and economy, and changing lifestyle in the world, especially in developing cities, are driving the increased demand of water and wastewater treatment. During this process, environmental pollution and ecological deterioration has been getting drastically worse, which brings huge challenges to the availability and safety of water sources, and increases difficulties in treating wastewater.

Within this context, the impacts of climate change, including rising sea levels, more frequent and intense rainfalls as well as extended dry periods, could cause further stress in an already insufficient urban water system. To address such issues, the current proposals are potentially very energy and carbon intensive. It is advisable to pay due attention to the water sector to reduce energy consumption and related CO_2 emissions, particularly in China.

China is the biggest developing country with 21% of the world's population, but also one of the most water-poor countries with only 6% of the world's freshwater (PwC 2013). Per capita water resource (2000 m^3) in China is just 25% of the global average. Even this number is estimated to shrink by 1700 m^3 in 2030, if population growth continues. Parallel to water shortage is the problem that the pollution of water sources is getting worse. According to China Water Resources Bulletin 2011, the water quality of 35.8% of the length of the river and of 41.2% of the lake was below class Ⅲ[19], which is not suitable for human consumption. Of 660 cities in China, more than 2/3 of them are facing water shortage problems, and more than 110 cities are in acute shortage (Carmody 2010). In order to deal with this issue, exploration of new water sources, such as inter-basin water diversion, groundwater pumpage, and seawater desalination, can consume an enormous amount of energy and will cause increased CO_2 emissions.

Moreover, China is among the countries that are most impacted by climate change. As sea level rise, precipitation patterns change, temperatures increase, and storm surges

[19] According to the Chinese Environmental Quality Standard of Surface Water (GB3838-2002) , the water quality can be defined into 5 classes, based on the surface water environmental functions and protected objects:
Class I: applied to head waters and national nature reserves;
Class II: applies to Grade-I protective zone of surface water resource area of drinking water, habitats for rare aquatic lives, spawning grounds and feeding grounds;
Class III: applies to Grade-II protective zone of surface water resource area of drinking water, wintering grounds and migration channels of fish and shrimp as well as aquaculture grounds and swimming areas;
Class IV: applies to ordinary industrial water areas and recreation areas without people's direct touch;
Class V: applies to agricultural water areas and ordinary scenery water areas.

intensify, the operations of the urban water systems will be increasingly compromised, notably in pre-urban areas and informal settlements. Even small perturbations of water supply, wastewater treatment, and storm water systems can threaten the informal systems greatly with service disruption, weakened capacity of flood storage, reduced water quality, and increased energy use and carbon emission for operation and maintenance.

3.5.2 Contribution of water to climate change

In urban areas, water and energy are inseparably linked together. Water needs to be captured at watershed areas, to be transported and lifted over obstacles, to be treated and heated; then, wastewater also needs to be treated, to be transported and disposed of. All of these steps require energy (Major, Omojola et al. 2011), and this implies the generation of carbon emissions in the case of fossil-fuel consumption. Although water systems are currently not major emitters of CO_2 in cities, they have the potential to reduce emission levels. Table 3.3 shows the estimated energy use and carbon emissions in China's municipal water and wastewater sector, which is based on the World Bank/WSP Shandong (2010) water utilities benchmarking study and International Energy Agency (2009) data on China's electricity emissions factor (Danilenko, Ikegami et al. 2012).

Table 3.3 Energy use and carbon emissions in China's municipal water and wastewater sector in 2010 and in 2020

	2010			2020 Forecast		
	Water	Wastewater	Total	Water	Wastewater	Total
Volume million cubic meters	50697	37400	----	67964	50137	----
Energy use (GWh)						
Energy use	25349	15708	41057	33982	25069	59051
Energy use with efficiency saving of 20% every five years	----	----	----	21748	16044	37792
Carbon emissions (million tonnes)						
China emission factor	20.03	12.41	32.43	26.85	19.80	46.65
China emissions factor with energy efficiency saving	----	----	----	17.18	12.67	29.86

Assumptions: Average water consumption remains 165 liters per capita per day. Wastewater collection and treatment rate will increase to 90% and unaccounted for water will remain at the level of 22% on average. Current energy demand will stay the same for water and wastewater.
Source: (Danilenko, Ikegami et al. 2012)

(1) Water supply

In water supply systems, a critical question many Chinese cities are facing is how to address the problem of water scarcity while meeting the increasingly stringent requirement on water quality.

In order to improve water quality, the Chinese central government started full implementation of the latest Standards for Drinking Water Quality (GB 57492006) in 2012. It increases the number of inspection items from 35 to 106 and imposes stricter limits. At the same time, though, the pollution of water sources of cities is becoming more serious. This will make the supply of quality consumable water more energy- and carbon-intensive, because of commonly needed higher levels of water treatment.

Moreover, under the combined effect of rapid growth of urban population, increased pollution, and climate change, the water shortage in Chinese cities is getting worse. When the common source surface water is inadequate or unsafe, actions to expand or improve the supply of water of an acceptable quality are inevitable, such as extraction of groundwater, long distance water transfer, and water desalination. These options have different effects on overall energy use, and are associated with carbon emission intensity.

Water-scarce cities, especially in northern China, are dependent generally on groundwater as the primary source. It accounts for 36.3% of northern China's water supply in 2005 (China Water Risk 2010). The large-scale exploitation and utilization of groundwater requires, on one hand, more pumping and treatment, thus resulting in more energy consumption and CO_2 emission; on the other hand, over-extraction of water from underground aquifers may draw the water table down, and could have serious consequences of land subsidence or seawater intrusion. For urban areas where the water demand has exceeded supply from local surface water and even groundwater, water becomes a crucial source of supply. An ongoing project – South-North Water Diversion Project is a representative example in China. It transfers water from Yangtze River in central China to the more arid and industrialized northern cities. This project will consume huge amounts of energy because of its long-distance and high-lift transmission. After all, in water-scarce coastal cities, desalinization of saline water may be utilized to supplement water supply. Such a process is also energy-intensive.

Most options discussed above, either for water quality improvement or for water supply exploration, require high energy consumption. Therefore, exploring more energy-efficient and low-carbon alternative measures addressing water issues should be the priority. In addition, efforts on demand reduction also need to be valued. Because the rational use of water resource can alleviate the pressure on water supply effectively along with CO_2 mitigation benefits.

(2) Wastewater treatment

Cities consume huge amount of water resource, while, they are a large wastewater producer. According to China Urban Construction Statistical Yearbook 2012, the total wastewater from cities reached 41.676 billion cubic meters by the end of 2012 (Ministry of Housing and Urban-Rural Development of the People's Republic of China 2013). In the process of transport, treatment, and disposal of such vast quantities of wastewater, significant greenhouse gases could be generated. The analysis of the emissions generally includes two categories:

- The gaseous emissions produced by wastewater degradation in non-oxygen conditions are called "direct emission". It consists mainly of CH_4 and N_2O. The impacts of CH_4 and N_2O on warming the atmosphere are, respectively, 40 times and 300 times stronger than CO_2 (Brummell and Siciliano 2011).

- The carbon emissions associated with the energy consumption by wastewater treatment facilities and equipment are "indirect emission". It is emitted during the processes of wastewater transportation, pumping, treatment, effluent disposal, residuals management, etc. (Listowski, Ngo et al. 2011).

In developed cities, the collection and management of urban wastewater are strictly controlled, in order to minimize the escape of gaseous emissions from this sector. Thus, reduction of emissions from wastewater treatment infrastructures, i.e. the indirect emission, has been identified as important actions for climate change mitigation. In developing cities, for example in China, without sufficient wastewater system, the decentralized 'natural' treatment processes may result in relatively large emissions of CH_4 and N_2O (Bates, Kundzewicz et al. 2008). Thereby, improved collection, treatment, and disposal infrastructures would be a direct way for GHG emissions, and additionally bring substantial public health benefits (Major, Omojola et al. 2011).

3.5.3 Impacts of climate change on water

Climate change will mainly manifest itself through alterations in the water cycle. As a result, the urban water system is at high climatic risk. The projected changes in climate phenomena such as changes in precipitation pattern and intensity, higher temperatures, more intense storms, and possibly rising sea levels, are expected to increase flooding and drought, exacerbate water pollution, and reduce water supplies (Bates, Kundzewicz et al. 2008). It will finally threaten urban water infrastructures with breakdown of service, decreased storage for potential emergencies, lowered water quality, and increased energy consumption for system operation and maintenance (Major, Omojola et al. 2011).

Increased frequency and intensity of precipitation will lead to more flooding and thereby cause destruction of the physical infrastructure of the urban water system, such as damage to pipelines and facilities, increasing sediment load of reservoirs, and broken defenses (Loftus 2011). In combined sewer systems, more intense rainfall can cause sewage overflows and consequent contamination of the nearby waterways and water bodies. More intense and frequent rainstorms can also raise turbidity levels of water due to soil erosion and enhanced transport of pollutants to surface waters and groundwater, ultimately resulting in degradation of water quality (Bates, Kundzewicz et al. 2008).

More intense droughts may result in decrease of surface runoff levels, thus exacerbating water shortage and threaten the security of water supply. Reduced precipitation also leads to less groundwater recharge and more groundwater extraction. This, in turn, would increase the energy use for pumping water from deeper groundwater levels. Altered precipitation patterns in winter will negatively affect the water storage in snowpack reservoirs. As a result, cities that depend on snow and glacier melt as their main source of water supply may be challenged by reduction in freshwater availability (Loftus 2011). Additionally, droughts will also cause disappearance of natural wetlands that aggravate the ecological risks.

Increased temperatures and related evapotranspiration will reduce water supply, and meanwhile, increase demands for all consumptive water uses (Loftus 2011). Besides that, water quality will be affected by the warmer air temperatures that can cause deterioration of chemical and biological features of water bodies (Bates, Kundzewicz et al. 2008). Indirectly, warmer temperatures will also result in higher demand for cooling water in the energy sector leading to increased thermal pollution (Kundzewicz, Mata et al. 2007).

As sea levels rise, the problem of saltwater intrusion will be more acute, which reduces the available potable water supply from coastal surface water and groundwater (Kundzewicz, Mata et al. 2007). Higher sea levels and more intense storm surges can also increase the occurrence of coastal flooding. This may cause damage to and degradation of infrastructures of water supply and wastewater treatment, consequently resulting in disruption of public water supply and sewer overflows.

3.5.4 Mitigation and adaptation strategy of water

In the context of increasing water scarcity and climate change, mitigation and adaptation strategies of the water sector in Chinese cities include: demand water reduction, water reclamation and recycling, and improvement of drought and flood prevention capacity.

Reducing water demands with efforts to make proper use of water and enhance water use efficiency will yield multiple benefits. The most direct one is to alleviate the pressure of water resource shortages. Reducing water demand can increase resiliency and security of existing water supplies (Major, Omojola et al. 2011), and help this sector to adapt to the impacts of climate change. Moreover, using less water means less need for water extraction, transportation, treatment, heating, and less need for wastewater transportation and treatment. Energy required by such activities and associated CO_2 emissions can be saved. The effective approaches of demand reduction involve pricing policies, leakage management, utilization of water-saving appliances, and behavior change.

Another strategy for reducing the energy consumption of water supply is **water reclamation and recycling** for non-potable uses. It is estimated that 40-60% of drinking quality water is used for non-potable demands such as industrial cooling, landscape irrigation, toilet flushing etc. (Martinez and Clark 2012). Water for drinking requires higher quality than for non-potable needs and thereby requires more sophisticated and energy-intensive treatment methods. Using reclaimed and recycled water for non-potable uses can decrease energy use and related emissions by reducing treatment requirements. Furthermore, since the reclaimed and recycled water is already in the city, energy demands of water extraction and transportation from sources can be saved, thus providing CO_2 emissions mitigation benefits. Apart from that, reclaimed and recycled water can also be used to create or enhance wetlands/marshlands that provide a buffer against flooding and raised sea levels. For instance, a rainwater collection and use program is instituted in the Harbin Qunli Stormwater Park to revive a dying wetland and transform it to an important flood diversion zone for the city.

Improving capacity of drought and flood prevention in a city can effectively minimize the impacts from the more intense and frequent floods, droughts, and extreme weather events on the urban water sector. This strategy covers a wide range of actions with regard to urban water supply, wastewater treatment and stormwater management. Expansion of water storage through aquifer storage and recovery is an important option for drought relief and supply security enhancement. Another option that should be considered is decentralized wastewater treatment techniques. Obviously, cities depending on one large wastewater treatment plant face more risks than cities with several small plants in different locations (Loftus 2011). Additionally, the energy consumption and cost of operating decentralized plants will likely be less than the centralized solutions. In respect to flood control, construction of seawalls and flood barriers are effective actions, while attenuation of runoff by rain and sewage diversion systems and green infrastructure application (e.g. green roofs, permeable pavement, etc.) can reduce potential flooding too.

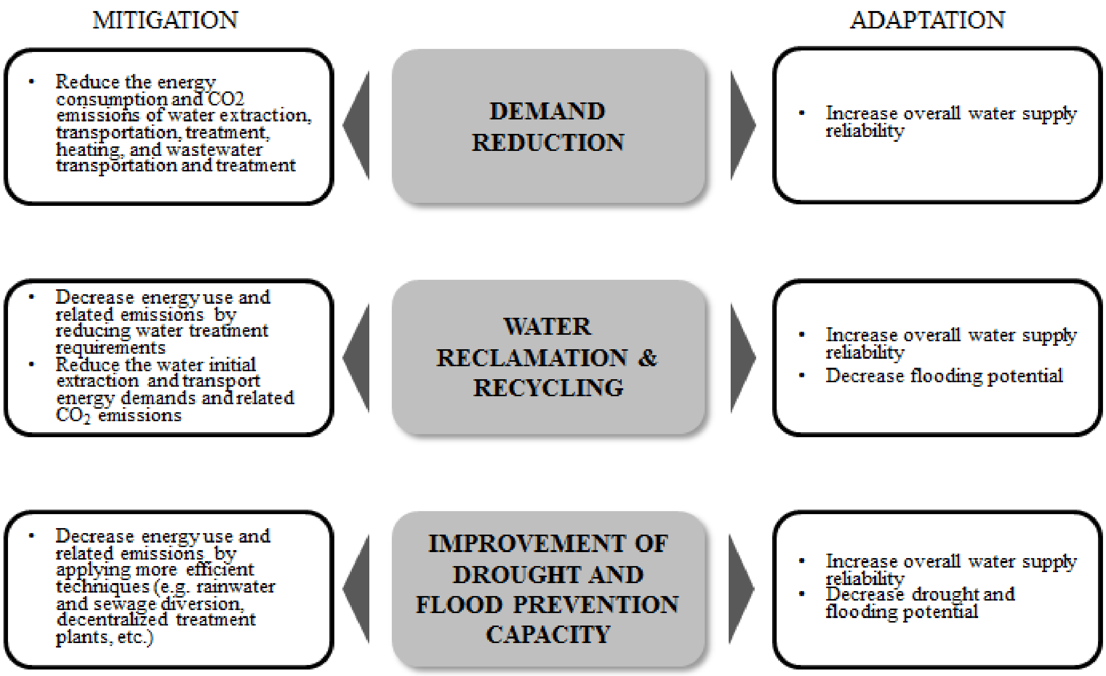

Figure 3.27 Climate change mitigation and adaptation of water

3.5.5 Water in low-carbon city evaluation

The impact of climate change on the water sector is mainly manifested in water supply, wastewater and stormwater systems. Hence, these are also the main aspects in low-carbon city evaluation.

Water supply is an important guarantee for the sustainable development of a city that is significantly vulnerable to expected climate change. As mentioned in 3.5.3, water shortage will be aggravated by more intense droughts, increased evaporation rates related to warmer temperatures, and saltwater intrusion caused by rising sea levels. Furthermore, another crucial component of water supply – water quality will also be negatively affected by flooding and increased air temperatures. According to a report released by China's environment authority in 2014, it was estimated that 280 million residents in China could not get access to safe drinking water. Those climatic impacts may add more pressures on Chinese cities that are already suffering water shortages. Under this condition, water demand management, water reuse, and water storage expansion are necessary approaches for enhancing the resilience of urban water supply, while reducing the requirements of energy-intensive water treatment and supply expansion.

Wastewater treatment is also an aspect that is greatly affected by changing climate conditions. Due to the anticipated increasing frequency of high intensity precipitation events and rising sea levels, wastewater treatment infrastructure can be physically damaged or functionally degraded. In cities with combined sewer systems, this will lead to more overflow events and untreated sewage into surrounding water bodies

(Kenward, Yawitz et al. 2013). Simultaneously, wastewater is a growing emitter of GHGs. As discussed in 3.5.2, "natural" treatment processes without proper control will cause massive emissions of nitrogen dioxide, methane, and carbon dioxide. Thus, wastewater treatment is no doubt an indispensable evaluation aspect of a low-carbon city.

Another aspect of concern is **stormwater management**, since it will be highly affected by increasingly frequent and intense precipitation. During heavy rainfalls, the storm-runoff can overwhelm the capacity of stormwater system, resulting in street flooding. A report by China's Ministry of Housing and Urban-Rural Development indicated that between 2008 and 2010, 62% of the 351 surveyed Chinese cities suffered from different levels of floods, and 39% experienced floods more than 3 times (Li, Wang et al. 2014). Therefore, in cities affected by increasing heavy storms, the capacity of stormwater systems and emergency response systems will need to be improved to prevent flooding.

3.6 Municipal solid waste

3.6.1 Municipal solid waste and climate change

Municipal solid waste (MSW) contributes to climate change through the generation of methane (CH_4), nitrous oxide (N_2O) and dioxide (CO_2) during the process of waste management and disposal. All can be identified as greenhouse gases with global warming potential of 40, 300 and 1 respectively (Brummell and Siciliano 2011). As the Intergovernmental Panel on Climate Change (IPCC) estimated, the waste management sector makes a contribution of approximately 5% of global anthropogenic emissions in 2005 (Bogner, Ahmed et al. 2007). Compared to other sectors discussed before, such as transport, building, and energy, waste is a relative small emission source. Nevertheless, it can become a carbon saver with sound waste management practices that provide immediate and cost-effective opportunities to achieve substantial carbon emission reductions.

The definition of MSW varies from country to country, reflecting different systems of waste management. For instance, it is defined as all waste generated within a municipal boundary that includes commercial, industrial, construction, and hazardous waste in Europe (UNEP 2010). In China, in compliance with "Law of the People's Republic of China on the Prevention and Control of Environmental Pollution by Solid Waste", solid waste is divided into three categories: municipal, industrial and hazardous waste. "Municipal waste" generally refers to household, institutional, and commercial waste; waste from street cleaning; non-process waste from industries; and construction and demolition waste in some cases (Hoornweg and Xie 2012). "Industrial waste" means the waste generated by industrial processes which is less hazardous to the environment and human health like slag, coal gangue, and industrial dusts, etc. "Hazardous waste" is the waste regulated under National Hazardous Waste Inventory, or tested to exhibit one or more of the traits of toxicity, corrosivity, reactivity, and ignitability according to the national identification standards that threatens environment and public health. The focus of this chapter is on municipal solid waste which is the main source of emissions from the waste management sector and relatively controllable at city level.

With the fast development of urbanization and the growth of GDP in China, the amount of waste increases dramatically. As shown in Figure 3.28, China generated about 170 million tonnes of MSW in 2012, rising by 11.5% when compared to amount number in 2006, with an average annual growth rate of 2.4% between 2006 and 2012. Because of this continuing rapid increase in MSW quantities, the waste sector becomes a significant source of GHG emissions in China. Despite a close link between growth in per capita MSW generation and rising affluence (Bogner, Ahmed et al. 2007), it is remarkable that countries which implement effective strategies of waste management and disposal always produce less waste than several other countries at similar stages of development. For instance, the levels of economic development of some developed members of the European Union are roughly the same as the United States, whereas their per capita municipal waste generations are lower than that of the US (Table 3.4). It verifies that waste generation is not only affected by a country's level of urbanization and affluence, but also its adopted strategy of waste management and disposal.

According to the experience of most countries, the development process of MSW management and disposal can be generally divided into four stages as the economy grows (Chinese Society for Urban Studies 2011). In the first stage, the waste output is moderate, and the composition is simple. In this period, open dump is the most common form of waste disposal, and the methane produced by the decomposition of the organic portion of waste is the main source of GHG emissions. In the second stage, cities produce more waste with relatively complex composition compared to the last stage. Sanitary landfill is the most common form of waste disposal for this period, and landfill gas is the major source of emissions. In the third stage, the conflict between the greatly increased waste output and limited land resources has become an important issue. For the purpose of waste minimization, MSW incineration is adopted more widely. The total emissions from incineration are almost the same as, or more than, emissions from landfill, and generate heavy metals and dioxins. In the fourth stage, as the environmental problems brought by MSW incineration get increasingly outstanding, integrated solid waste management (ISWM) becomes the developing tendency that achieve significant GHG emission reduction through the approach of 3R – Reduce, Recycle, and Reuse (UNEP 2010).

Currently, the waste generation and management in China follow the same transition process as many other countries. Most large and medium-sized Chinese cities are at the third stage or even earlier. Therefore, the development and optimization of MSW management is necessary to solve the problem of GHG emissions from the aspect of waste handling.

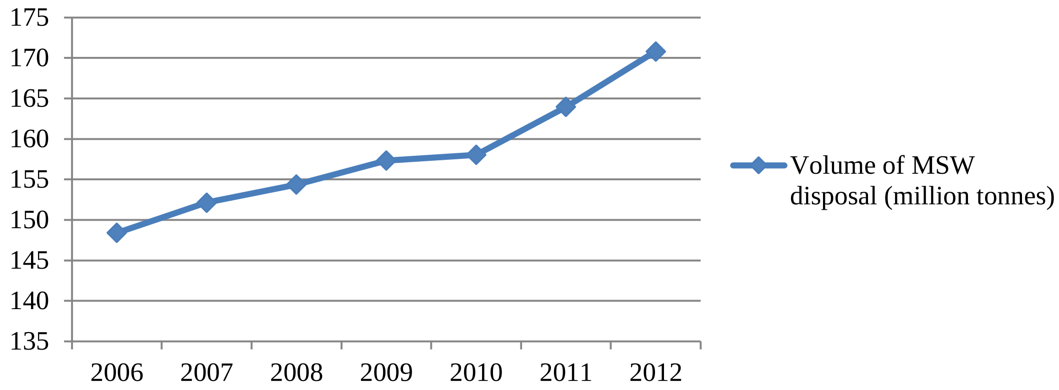

Figure 3.28 Volume of municipal solid waste disposal in China 2006-2012

Source: (State Statistics Bureau of China 2007-2013)

Table 3.4 MSW generation and GDP per capita of US and some EU countries (2011)

Countries	Total MSW generation (thousand tonnes/year)	Per capita generation (kg/person/day)	GDP per capita (current US$)
USA (2011)[a, d]	250400	2.00	49854
Austria (2011)[b, c, d]	----	1.53	49485
Belgium (2011)[b, c, d]	5035	1.29	46464
Denmark (2011)[b, c, d]	4001	1.98	59898
Finland (2011)[b, c, d]	2719	1.37	48678
France (2011)[b, c, d]	35019	1.45	42560
Germany (2011)[b, c, d]	50237	1.64	44355
Ireland (2011)[b, c, d]	2823	1.75	49387
Italy (2011)[b, c, d]	31386	1.48	36180
Luxembourg (2011)[b, c, d]	345	1.92	111913
Netherlands (2011)[b, c, d]	9479	1.64	49886
Spain (2011)[b, c, d]	22672	1.37	31118
Sweden (2011)[b, c, d]	4374	1.26	56755
United Kingdom (2011)[b, c, d]	31066	1.45	39186

Source: a (U.S. EPA 2013); b (OECD 2011); c (OECD 2013); d (The World Bank 2011)

3.6.2 Contribution of municipal solid waste to climate change

The lifecycle of waste can be described as a journey from cradle to grave – that is, from when products are put in the dumpster to when value is restored by creating usable material or energy, or the waste is transformed into emissions to water or air, or into inert material placed in a landfill (White, Franke et al. 1995). This process includes activities of waste collection and transport, recycling/composting, and disposal (incl. incineration and landfilling) that play different roles in waste management and impact GHG emissions (Figure 3.29).

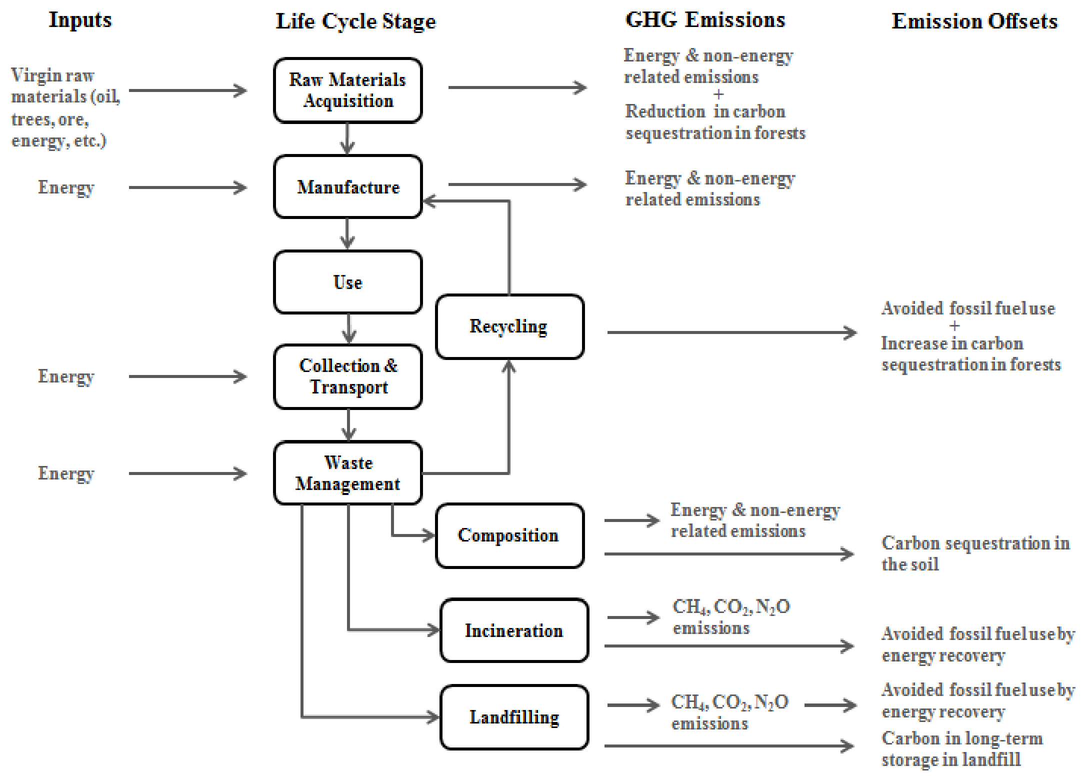

Figure 3.29 MSW management-related GHG sources and offsets
Source: (U.S. EPA 1998, Weitz, Thorneloe et al. 2002)

(1) In cities with rapidly growing populations, the rising amount of waste often results in demand growth for MSW collection and transport, and associated energy consumption and carbon emissions. During the collection and transport of MSW, GHG emissions mainly originate from burning fossil fuel (petrol or diesel) for waste collection and transport vehicles that are affected by multiple factors, such as vehicle type, payload, haul distance, etc. (Liu and Zhou 2013).

(2) Recycling makes use of certain products (e.g. glass, paper, metal, etc.) that otherwise would become waste (U.S. EPA 2002). Composting is another form of recycling that biodegrades organic waste (e.g. food scraps, manure, plant matters, etc.) into soil additives. Recycling and composting deliver GHG emission savings in two ways: i) displacement of virgin raw materials, thus, avoiding emissions from raw materials extraction, products manufacture, materials and products transportation; ii) diversion of waste materials from landfills that generate GHGs (Weitz, Thorneloe et al. 2002).

(3) Incineration is a common method of waste disposal that involves the combustion of organic substances contained in waste materials to reduce its volume (Knox 2005). During this process, GHG sources generally include: i) emissions of carbon dioxide (CO_2) and nitrous oxide (N_2O) resulting from fossil fuel combustion; ii) emissions of CO_2 resulting from combustion of waste containing fossil carbon (e.g. plastics); iii)

emissions of methane (CH_4) resulting from anaerobic digestion of leachate in incineration plants (Bogner, Ahmed et al. 2007). In some cases, the heat provided by burning waste can be recovered to produce electrical power. This contributes to the mitigation of GHG emissions by displacing power generated from fossil fuels.

(4) Landfill is the most widely-used way of waste disposal, meanwhile a significant contributor of GHG emissions. In landfill sites, the sources of GHGs include: i) landfill gas (mainly CH_4 and CO_2) emitted by the decomposition of the organic portion of MSW; ii) CH_4 and N_2O from landfill leachate tank; iii) CO_2 from energy consumption for auxiliary processes (Xu and Liu 2010). From another view, landfill gases can be captured and recovered to produce electrical power, which deliver a benefit in emission reduction from the avoided emissions of other alternative energy. In addition, a noteworthy amount of biogenic carbon (e.g. wood, paper, food scraps, etc.) that are not degraded after disposal may remain in the landfill for very long periods of time. This carbon sequestration is counted as a carbon balance.

3.6.3 Impacts of climate change on municipal solid waste

Climate change will have adverse effects for the future development and operation of municipal solid waste management facilities and infrastructures in a variety of ways, since it could cause changes to numbers of factors affecting waste management processes. The potential impacts across the MSW sector usually include (Bebb and Kersey 2003, Zimmerman and Faris 2010, The World Bank 2011, U.S. EPA 2013):

- Increased damage of constructions of waste management sites due to the potential intense rainfalls and storm events, and related secondary disasters.

- Higher risk of slope instability at waste management sites from more intense precipitation events.

- Increased disruptions in the supporting infrastructure and transportation of MSW attributing to increases in heavy rainfall events.

- Greater incidence of flooding due to heavy precipitation, storm surges, and rising sea levels could increase the risk of contaminant spread. For instance, flooding in areas of untreated waste could cause the spread of environmental pollutants, and threaten public health.

- Coastal flooding and erosion due to higher sea levels could damage facilities and equipment at low-lying sites.

- Biological waste management process, such as composting and anaerobic digestion, will be affected by hydrology and temperature changes in site.

- Melting permafrost resulting from warmer temperatures could affect water systems around landfill sites.

- Warmer temperatures could increase the risk of fires at open dumpsites and composting sites.

- Increased temperature could increase the activity of pathogen and vermin in sites that result in spread of vector-borne diseases.

Already, there are events proving that the current MSW management is insufficient and vulnerable to the expected climate change even in developed countries. As one example, in 2002, a serious flood of Elbe River in Germany caused by extreme rainfall created landfill and dumpsites erosion and released environmental pollutants of in heavy metal and arsenic that resulted in significant pollution (FONA).

3.6.4 Mitigation and adaptation strategy of municipal solid waste

Municipal solid waste management involves a series of steps, including waste collection and transport, recycling/composting, and disposal. Each of the steps could provide considerable opportunities for GHG saving, when the system of waste management is well-designed (Hoornweg and Xie 2012). Globally, a number of organizations have a consensus across the municipal solid waste sector that significant benefits for climate change mitigation and adaptation could be achieved through activities of waste prevention and waste recycling.

Waste prevention refers to the reduction of the amount of waste generated. This strategy includes i) using less packaging to eliminate excess material while maintaining function—as an important cause of the increase in waste volume, packaging waste represents about 30% of MSW; ii) designing and manufacturing durable/reusable products to prolong the useful life of the materials, in turn, to delay final disposal; iii) redesigning products to use less raw materials, usually the fewer materials are used, the less waste is produced (U.S. EPA 2002). The waste prevention strategies could deliver multiple benefits: reducing the need for material extraction and manufacture of new products, decreasing the amount of waste that must be transferred, recycled, and disposed, and extending the lifetime of landfills. As a result, less energy will be needed for these processes and ultimately fewer carbon emissions will be generated from the MSW sector.

China is currently experiencing a rapid increase in waste generation, and this trend seems to be sure to happen in most Chinese cities. In this context, waste prevention will be the inevitable choice of waste management to decoupling the waste generation from economic growth in China.

Waste recycling is to minimize the waste by material recovery and energy recovery when waste generation is unavoidable, including forms of recovering certain waste materials (e.g. paper, glass, metal, etc.), composting, and recovering energy from MSW incineration. Recycling rate refers to the amount of source-segregated waste in relation to the total amount of waste generation (Li and Liu 2010). Thereby, to recycle effectively, waste segregation is the critical prerequisite that can significantly improve the potential of waste recycling and the quality of compost and recyclables, and optimizes incineration (Hoornweg and Xie 2012). After waste prevention, recycling is another strategy substantially curbing the rapid-growing waste generation. In Figure 3.30, from 2002 to 2012, the total German generation of MSW decreased from 52.8 million tonnes to 49.2 million tonnes, while the recycling rate increased from 56.1% to 64.5%. This result comes down to the strict implementation of waste segregation in Germany (separate collection of packaging waste, bio-waste, waste paper, glass, etc.) (Fischer 2013). Recycling of MSW generates numbers of climatic, environmental and economic benefits, i.e., reducing the level of carbon emissions through less use of virgin materials and more use of energy from non-fossil MSW incineration, supplying valuable resources (e.g. compost), improving environment though waste minimization, and creating employment opportunities and income.

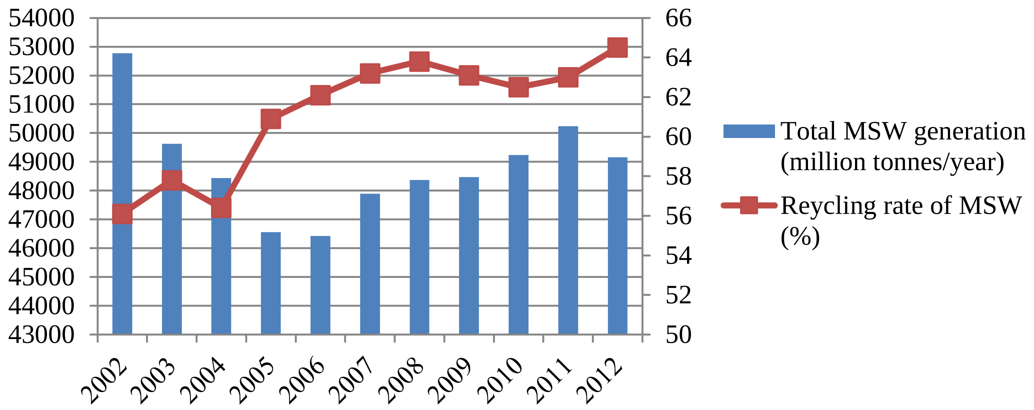

Figure 3.30 Total MSW generation and recycling rate in Germany 2002-2012
Source: (German Federal Statistics Office 2013, Eurostat 2014)

In China, the development of waste recycling is restrained by the absence of transformative policy for waste segregation. As an example, the recycling rate of the capital city – Beijing, is just less than 15% (Xiao, Bai et al. 2007). This level lags behind compared with most developed countries.

In addition to their mitigation contributions, strategies of waste prevention and recycling can also substantially reduce the demand for landfill and extend the lifetime of landfills, thus reducing the adaption costs.

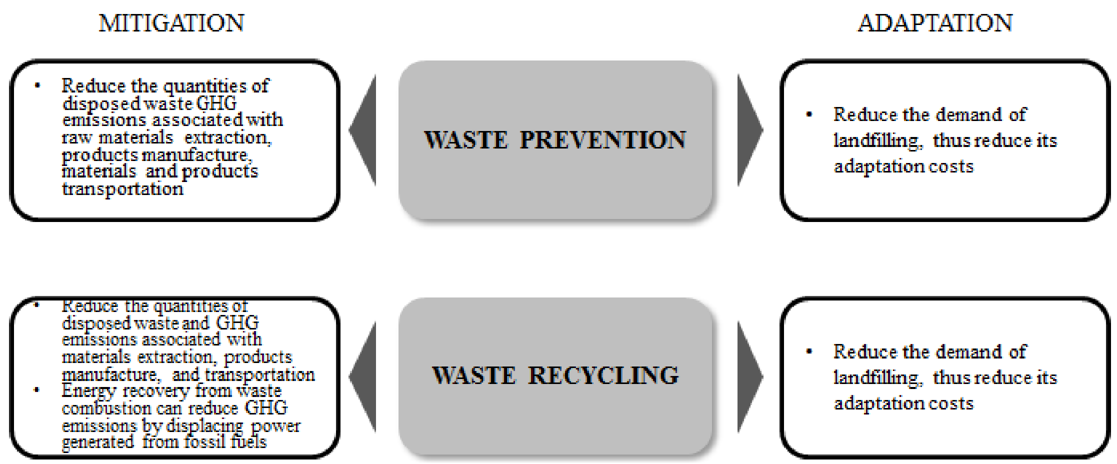

Figure 3.31 Mitigation and adaptation of MSW

3.6.5 Municipal solid waste in low-carbon city evaluation

Municipal solid waste management systems usually include an operational chain of collection and transport, and disposal. These processes on one hand generate carbon emissions, and on the other hand they are subject to climate change.

Waste collection and transport would be a crucial link to a successful MSW management system, since insufficient collection and transport services cause a series of problems, such as contaminating the environment, increasing flood risks, and threatening public health. Additionally, MSW collection and transport with proper waste separations can greatly increase the quality of materials for recycling and optimize incineration, in turn delivering benefits in CO_2 emission savings (Hoornweg and Xie 2012). One study in 2001 suggested that by separating food, garden, and pater waste to recycling, thus decreasing the organic fractions in landfills, emissions could be reduced by 260kg CO_2-equivalent per tonne of MSW (Smith, Brown et al. 2001). In China, there is still space for improvement in waste collection and transport. The existing waste collection and transport systems in Chinese cities are often unable to keep up with the growing demand for service driven by rapid urbanizations. Moreover, the lack of waste classification has further hindered the improvement in China's municipal solid waste management sector.

GHG emissions from **waste disposal** are mainly attributed to waste combustion and landfilling, including CO_2 emissions from incineration plants and methane from landfills (U.S. EPA 2002). It is regarded to represent the biggest impact on the climate from the waste sector. Currently in China, landfill is the most used method of MSW disposal amounting to 81.75% of the total disposed waste, followed by incineration accounting for 15% (Li and Liu 2010). But most of the landfills are insufficient in proper gas and leachate collection and treatment, and most of the incinerators are without energy recovery facilities. This has negative consequences on public health, environment and climate, so improvement of waste disposal is necessary for low carbon cities.

Chapter 4 Development of Low-Carbon Indicator System – Sino

4.1 Mode, framework, results of Low-Carbon Indicator System – Sino

Low-Carbon Indicator System – Sino (LCISS) is a low-carbon city evaluation system developed through learning from the experience drawn in the "Cooperative Project Shanghai: Integrated Approaches towards a Sustainable and Energy-Efficient Urban Development – Urban Form, Mobility, Housing and Living"[20]. This project is a part of "Future Megacities" research program launched by German Federal Ministry of Education and Research (BMBF) in 2008, and it was entrusted to the Institute of City Planning and Urban Design of University of Duisburg-Essen as the acting research group. The main outcome of this project is a tool – "Low Carbon Index (LCI®)" (Appendix 8) to evaluate urban areas regarding their energy-efficiency and CO_2 emissions. As a new method of low-carbon city evaluation, it has been tested in the Shanghai Hongqiao Low Carbon Business Center case study. According to the application feedback, LCI® still has some insufficiencies: i) not enough attention is paid to climate change adaptation strategy; ii) inadequate consideration of some significant urban sectors in low-carbon city evaluation, such as water and municipal solid waste; iii) lack of flexibility in adapting to cities with different social, environmental and economic conditions; iv) weak operability in the context of Chinese cities. These problems pointed out the improvement direction for the development of LCISS.

LCISS is composed of three parts: "indicator list", "evaluation checklist and report", and "development guideline". The main body of LCISS "indicator list" as an evaluation tool is a comprehensive indicator system that is constructed through coupling urban planning and sectors involved in low-carbon actions. "Evaluation checklist and report" is an evaluation result as well as a systematic review of a city's low-carbon development status. "Development guideline" is an action plan that describes which improvement is needed in the future.

Evaluation within LCISS is a circularly ascending process (Figure 4.1). It follows the sequence of applying "indicator list" to evaluate a city's low carbon development; summarizing status with "evaluation checklist and report"; supporting decision-making with "development guideline"; improving the city's next planning. Through this continuous process, experience could be summarized and lessons could be learned for future development.

[20] http://future-megacities.org/index.php?id=12#c213

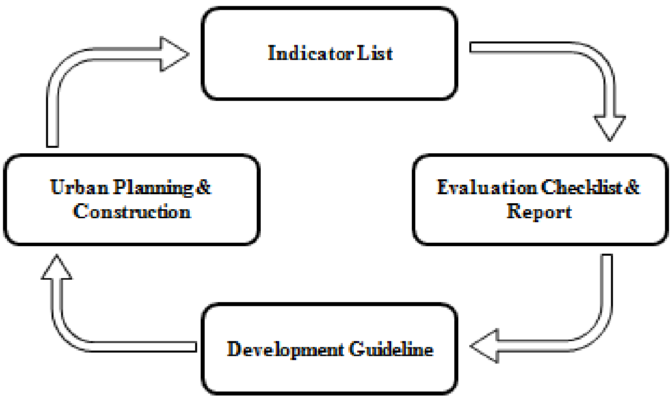

Figure 4.1 Evaluation process of LCISS

4.1.1 Mode

(1) Comprehensive indicator system

City is a complex giant system consisting of various subsystems and elements connected/interacted with various relations. According to this characteristic, the level of a city's low-carbon development is not determined by one specific factor, but related to synthetic effects of multiple-factors. Previous research in low-carbon city evaluation attempted to address this complex problem in a simplistic way, whereas they may be too aggregated to be meaningful measurements of whether a city is a real low-carbon city and do not provide any indication of where the shortcomings occur or where actions can be targeted. On the other hand, excessive emphasis on the complexity of low-carbon city tends to go to the other extreme. It will make the problem difficult to understand and solve.

Instead of both approaches, the comprehensive indicator method could offer a better way for evaluating low-carbon cities. It is one of the main methods to work with complex objects that analyze an object with various related indicators, in order to reflect the overall characteristics of the object. In this work, this method is applied to identify decisive factors of a city's low-carbon development level and establish a comprehensive indicator system with indicators closely related to the decisive factors.

(2) Coupled mode

In physics, two or more systems are coupled if they are interacting and influencing each other. In the process of developing a low-carbon city, actions to respond to climate change are coupled with urban planning.

As an important basis of city construction and management, urban planning has a major impact on the implementation of climate mitigation and adaptation actions, because the current climate initiatives, technologies and approaches often involve urban sectors which are concerned in urban planning, particularly in six key sectors mentioned in

Chapter 3: urban design, transport, energy, building, water, and municipal solid waste. Therefore, urban planning plays a role as a platform, in which the low-carbon actions can be integrated to, and then corresponding policies, standards, and supervision mechanisms can be formulated, so as to ensure those actions can be effectively implemented at a local level. On the other hand, to institutionalize low-carbon actions into the urban planning system could help the city to shift the development goal from promotion of economic construction to low-carbon development.

Based on the above analysis, establishing a coupled evaluation model with urban planning and key urban sectors that concentrate on most low-carbon actions is an optimal way to evaluate a city's low-carbon development level on different planning scales, and to indicate the inefficiencies of different urban sectors. This can effectively help the decision-maker to develop improvement measures, and ultimately realize the goal of low-carbon city development.

4.1.2 Framework

As mentioned, "indicator list" is the evaluation tool of LCISS, which is a comprehensive indicator system, constructed through coupling urban planning and key urban sectors. It includes three planning scales, i.e. macro, middle and micro scales, and six sectors: urban design, transport, energy, building, water, and municipal solid waste (MSW) (Figure 4.2).

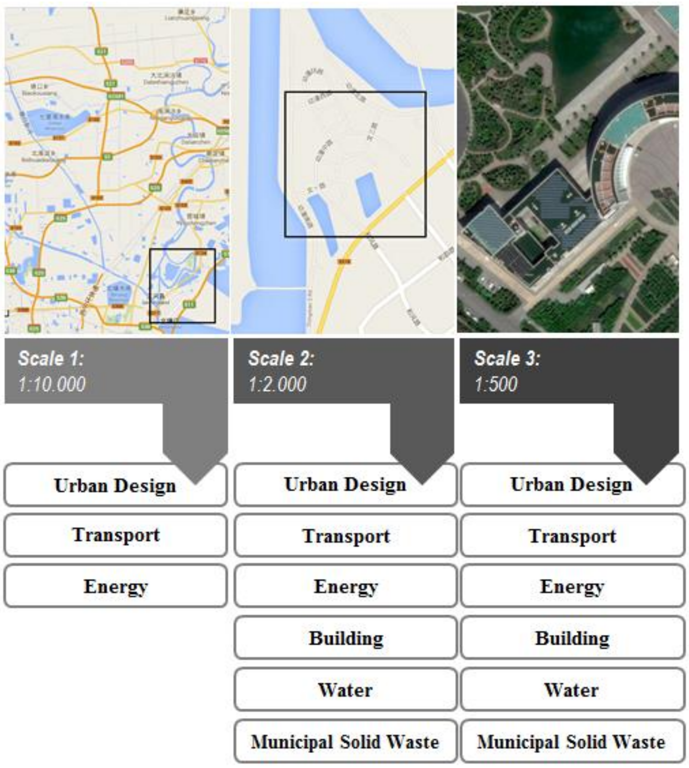

Figure 4.2 Framework of indicator list

(1) In the frame of the Chinese urban planning system[21], urban planning includes overall plan, regulatory detailed plan, and site detailed plan that correspond to macro, middle and micro planning scales. In the planning process, the conceptual planning ideas are developed, which are increasingly made more concrete and detailed. The evaluation of LCISS follows the same process.

- Scale 1: evaluation starts from macro planning scale (1:10,000), a large scale with little information and parameters. During this stage, the city's structure and overarching development strategy are taken into consideration. Attention should be paid to the following issues: urban form, land use pattern, transportation network, development direction of energy, infrastructure construction, etc.

- Scale 2: in the middle planning scale (1:2,000), further details evolve. Evaluation carries on in a smaller scale, down to the level of land use plans or special-purpose plans, such as a special plan for urban transport, water supply and drainage, energy, and municipal solid waste.

- Scale 3: micro planning scale (1:500) is the smallest scale with most details, in which evaluation focuses on urban construction and policy initiatives concerning technology and management of building, transport, energy, water, etc.

Since the specific targets of development and construction in three planning scales are different from one another, evaluations of them are conducted with different indicators. However, the indicators of the bigger scales could be maintained in the smaller scales and the evaluation of the bigger scale is accepted with less significance.

(2) As mentioned in Chapter 3, at the city level, most of the low-carbon actions focus on the following six sectors:

- Urban design is the key to success in low-carbon development. It determines the spatial and geographical layout of buildings and infrastructures (The World Bank 2011), in turn has considerable impact on energy use, resource consumption, and the climate change adaptation and mitigation ability of a region. In this sector, low-carbon actions aim to optimize urban spatial structure and land use through promoting the development of compact urban growth, mixed land use, transit oriented development (TOD), and green infrastructure.

- Transport is interpreted to be one of the key and growing sources of CO_2 emissions. It accounted for 22% of energy-related carbon dioxide emissions globally (International Energy Agency-IEA 2012). Moreover, urban transport is vulnerable to climate change impacts. In this sector, the objective of low-carbon actions is to

[21] Urban and Rural Planning Law of the People's Republic of China, Article 2 "…City or town planning includes overall planning and detailed planning. Detailed planning includes regulatory detailed planning and site detailed planning…"

reduce travel or the need to travel, promote climate-friendly transport modes, and improve the efficiency of motorized transport.

- Globally, carbon-intensive fossil fuels such as coal/peat, oil and natural gas are the main source to meet energy demand. It contributes to climate change, and at the same time, causes serious environmental pollution and energy crisis. On the other hand, energy supply and demand in cities is also impacted complicatedly by the anticipated climate change effects. Low-carbon actions in this sector focus on optimizing energy production and consumption structure, and controlling energy demand.

- The building sector is estimated to consume over 40% of total primary energy worldwide, and contributes 30% of the world's annual GHG emissions (United Nations Environment Programme - Sustainable Buildings & Climate Initiative 2009). The main issues of low-carbon actions in this sector are green building generalization, building energy efficiency improvement, and to push for large-scale application of renewable energy in buildings.

- Water is a sector that is not currently a major carbon emitter, but it has great potential to lower emission levels. Impacts of climate change, such as rising sea levels, more frequent and intense rainfall as well as extended dry periods, could cause further stress in already insufficient urban water systems. The solution of this problem may require huge amounts of energy and emit CO_2. Meanwhile, the operations of the urban water systems will be increasingly compromised with all mentioned effects. In sector of water, low-carbon actions include water demands reduction, water reclamation and recycling, and improvement of drought and flood prevention capacity.

- Municipal solid waste is a fast-growing carbon emitter, representing approximately 5% carbon emissions in urban areas. With sound waste management practices, MSW can become a carbon saver that provides immediate and cost-effective opportunities to achieve substantial carbon emission reductions. In this sector, low-carbon actions are mainly related to MSW prevention and MSW recycling.

4.1.3 Function

By applying LCISS, users will be able to:

- Assess the performance of different sectors on different planning scales, and systematically review the low-carbon development status of a city.

- Obtain a robust indication of where inefficiencies occur as well as where action is needed so that a city can become more "low carbon". Moreover, the history and trend of a city's low-carbon development could be revealed by comparing its evaluations at different periods.

- Define gaps and assess potential for improvement, and formulate action guideline to orient low-carbon city development in the future.

- Identify the potential solution. Through continuous evaluation and optimization of city planning and construction, LCISS helps city to achieve the goal of low-carbon development.

From the point of view of city development, LCISS plays an important role in monitoring and directing low-carbon city development. In the planning stage, it could rate the specific plans in terms of adaptability and the ability to reduce climate change in a traceable manner early on, in order to pinpoint errors in planning from a low-carbon standpoint, and correct the plan to resolve those errors. In the construction stage, it could periodically evaluate the city construction status, and then ensure the "low-carbon" direction of city development. For existing cities, the evaluation result of LCISS could be applied as a basis and guide for planning various kinds and various levels of urban redevelopment projects, with the aim of renovation to mitigate and adapt to climate change.

4.1.4 Products

The LCISS evaluation can yield three products: evaluation checklist, evaluation report, and development guideline.

(1) Evaluation checklist

Evaluation checklist is the intuitive result of the overall evaluation of a city with LCISS. Checklists for every key sector and every planning scale can clearly identify potential for optimization.

(2) Evaluation report

Evaluation report is a comprehensive review and summary for a city's low-carbon construction grounded on evaluation checklist. The comprehensive evaluation value (see 4.2.6) of each planning scale is calculated, the pros and cons of every evaluation sector would be analyzed, and improvement suggestions in the light of local conditions would be proposed. The main contents of the report include: overview of the low-carbon development in a targeted city (incl. comprehensive evaluation value), analysis of performance in all sectors, and challenge of low-carbon development.

(3) Development guideline

Development guideline is developed on the basis of analysis results and suggestion in evaluation report. Targeted action plans are formulated for each problem of different sectors on different planning scales, which provide support for government decision-making. It includes recommendations for possible actions against weak points. The main contents include: recommendation for low-scoring items, involved planning scale, and action responsible department.

4.2 Construction of Low-Carbon Indicator System – Sino

As mentioned above, the Low-Carbon Indicator System – Sino evaluates a city's "low-carbon performance" of different sectors on different planning scales by using adequate indicators, and forms a series of results on a comparable and traceable basis. In this process, the indicator list of LCISS plays a key role. Thereby, the organization of the indicator list is an essential step in the development of LCISS. It mainly contains the following steps.

- Indicator hierarchy – for simply and accurately illustrating the complex relationship among indicators, LCISS is built in a hierarchic structure with a three-level evaluation indicator.

- Indicator selection – in accordance with relevant, independent, systematic, and measurable principles, indicators of LCISS are selected via two rounds of questionnaire surveys and numbers of interviews with experts.

- Indicator type – the carbon-reduction potential and climate vulnerability vary from city to city, according to the size, natural environment, economy and social development, etc. For developing an extensively applicable evaluation system, indicators in LCISS are classified into essential type and expanded type.

- Indicator value – standard values of indicators are determined in light of the existing research results and successful experience drawn in pilot projects with adjustments based on China's actualities.

- Weighting Assignment – indicator weights are determined by following the Analytic Hierarchy Process (AHP) and Delphi methodology.

- Complex Value Calculation – evaluation values of three planning scales are calculated by using the weighted sum method.

4.2.1 Indicator hierarchy structure

LCISS is an evaluation system involving three planning scales, and six urban sectors. For each planning scale, a three-level evaluation indicator system is built in hierarchic structure. From first-class to third-class, indicators are from general to specific.

(1) First-class indicators are the six key urban sectors discussed in Chapter 3, including urban design, transport, energy, building, water, and municipal solid waste.

(2) Second-class indicators are as follows:

- Under the first-class indicator of “urban design”, second-class indicators include site planning, land use, accessibility, and green open space. “Site planning” is the first critical step of urban development, since the location and physical conditions of a city are the determinants of the city’s vulnerability to climate change. “Land use” planning is to balance the competing requirements of various functions on limited urban space and, further, the spatial distribution of the functions determines urban form that affects energy consumption and carbon emissions from many sectors, ranging from housing to transportation. “Accessibility” is the ultimate goal of most transport activities (Litman 2008). To improve a city’s mobility and accessibility by promoting development of public transport, could efficiently decrease the need of motorized individual traffic and associated CO_2 emissions. “Green open space” could play a constructive role in regulating temperature, providing green shades and managing flood risks, thus, helping cities to mitigate the heat island effect and adapt to increased precipitation events.

- Under the first-class indicator of “transport”, second-class indicators include individual motorized transport, public transport, non-motorized transport, and freight transport. “Individual motorized transport” is a critical factor that has undoubtedly the largest transport-related carbon emissions per capita in urban transport system. “Public transport” and “non-motorized transport” are the essence of a low-carbon urban transport system, since they provide a variety of benefits: efficient space use, less infrastructure and facility requirement, low/no carbon emissions and low/no air pollution. Additionally, “freight transport” is also evaluated as it provides a significant source of carbon emissions, especially the road-based mode.

- Under the first-class indicator of “energy”, second-class indicators include supply side, and demand side. In the sector of energy, carbon emissions can be reduced through developing low-carbon energy in energy supply side, and improving energy efficiency and demand control in energy demand side.

- Under the first-class indicator of “building”, second-class indicators include new and existing buildings. On one hand, China has become the biggest real estate market in the world, with up to 2 billion square meters of new constructions every year. On the other hand, China has 40 billion square meters’ of existing buildings, but only 1% of them hit the energy-saving target. Therefore, both new and existing buildings play an important role in low-carbon city development.

- Under the first-class indicator of “water”, second-class indicators include water supply, wastewater treatment, and rainwater storage & drainage. Water supply is an important guarantee for the sustainable development of a city that is significantly vulnerable to the expected climate change. Wastewater treatment is a growing carbon emitter, while it is highly sensitive to climate changes. Rainwater storage and drainage directly determines whether a city could be resilient to the possible changes in precipitation patterns brought about by climate change.

- Under the first-class indicator of “municipal solid waste”, second-class indicators include MSW collection & transfer, and MSW disposal. Proper MSW collection and transfer could not only benefit climatic mitigation, but also efficiently prevent a series of problems, such as contaminating the environment, increasing flood risks, and threatening public health. MSW disposal is regarded to represent the biggest impact on the climate from the sector of waste.

(3) Third-class indicators include 54 items (Table 4.1) that are independent but interrelated.

Table 4.1 Indicator list of LCISS

First-class indicators	Second-class indicators	No.	Third-class indicators	Indicator type	Evaluation scale
Urban design	Site planning	1	Original land use type	essential	123
		2	Disaster risk	essential	12
	Land use	3	Mixture of functions	essential	123
		4	Urban development land area per capita	essential	23
		5	Small-scale block	essential	23
	Accessibility	6	Regional traffic connection	essential	123
		7	Transit-oriented employment density	essential	23
		8	Transit-oriented residential density	essential	23
	Green open space	9	Greenery coverage ratio	essential	23
		10	Coverage ratio of green space service radius	essential	23
		11	Quality of green open space	expanded	3
Transport	Motorized individual transport	12	Position in highway network	essential	1
		13	Road network density	essential	2
		14	Car park management	essential	3
		15	Recharging devices of E-mobility	expanded	3
		16	Car sharing	expanded	3
		17	Prioritization for low emission vehicles	expanded	3

	Public transport	18	Main form of Mass Rapid Transport	expanded	1
		19	Connection to the major origins and destinations	expanded	2
		20	Transit station coverage	essential	2
		21	Velocity of public transport	essential	3
		22	Average wait-time in the highest peak hour	essential	3
		23	Emission level of buses	essential	3
		24	Quality of public transport vehicles	expanded	3
		25	Quality of public transport stations	expanded	3
	Non-motorized transport	26	Connectivity of footpaths	essential	2
		27	Quality of footpaths	essential	3
		28	Connectivity of cycle tracks	essential	2
		29	Quality of cycle tracks	essential	3
		30	Non-motorized vehicle parking	essential	3
	Freight transport	31	Main freight transport modes	essential	1
		32	Prioritization for low emission trucks	expanded	3
Energy	Supply-side	33	Main sources of energy supply	essential	123
		34	Renewable energy production	essential	23
		35	Electricity production by co-generation	essential	23
	Demand-side	36	Green electricity contract	expanded	3
		37	Incentive policy of renewable energy utilization	essential	3
		38	Metered heating rate	essential	3
Building	New buildings	39	Qualification ratio of building energy efficiency in new buildings	essential	23
		40	Proportion of green buildings in new buildings	essential	23
	Existing buildings	41	Qualification ratio of building energy efficiency in existing buildings	expanded	23
Water	Water supply	42	Water supply from non-traditional sources	essential	23
		43	Water tariff	essential	3
		44	Leakage rate	essential	3
		45	Coverage of water-saving appliances	expanded	3

	Wastewater treatment	46	Treatment rate of wastewater	essential	23
	Stormwater management	47	Stormwater and wastewater diversion	essential	23
		48	Drainage system	essential	23
		49	Flood prevention	essential	23
Municipal solid waste	MSW collection & transfer	50	Waste collection rate	essential	23
		51	Proportion of communities with separate waste collection facilities	essential	3
		52	Emission level of waste transport vehicles	expanded	3
	MSW disposal	53	Landfilling rate	essential	23
		54	Harmless treatment rate	essential	23

4.2.2 Indicator selection

(1) Principles of indicator selection

The following are requirements that an indicator must fulfill for it to be accurate, simple, relevant, and standardized for policy and measurement purposes:

· Relevant: The indicators should reflect certain aspects or characteristics of the evaluation object. There should be a clear link between low-carbon city and each indicator.

· Independent: The relations of indicators should be analyzed by the selection process, in advance, to ensure that each indicator is independent of the others and there is no overlap and causality relation among indicators.

· Systematic: The indicator system is an organic whole systematically reflecting all aforementioned sectors of a city. It is composed of indicators that are independent and yet connective to each other. An indicator combined with other indicators should add a greater understanding than a simple superposition.

· Measurable: The main motivation for construction of LCISS is to measure and evaluate the city's climate change mitigability and adaptability of a city. Thus, the selected indicator should be cost-effectively measurable, statistically accurate, and supporting data and preferably calculation models should be available. Furthermore, the indicator would comply with local and national policies and institutions that might be involved in the implementation.

(2) Method of indicator selection

The methods of indicator selection mainly involve empirical and mathematical methods. The empirical method is represented by the Theoretical Analysis method and Delphi method. Indicators are selected based on extensive analysis of relevant theories, while giving full scope to the professional knowledge and experience of experts. This method inevitably possesses certain subjectivity. The mathematical method typically includes frequency analysis method, factor analysis method, variance analysis method, principal component analysis method, etc. With this method, indicators could be selected through quantitative analysis. Repeated indicators could be eliminated with more objectivity. Nevertheless, the connotation of the object cannot be clearly confirmed using this method, so in some cases the indicator selection is meaningless. Moreover, with the mathematical method, the uniqueness of the result cannot be guaranteed when the adopted sample set changes (Du, Pang et al. 2005). In general, there is no recognized method for indicator selection, but the effect of expertise is widely accepted in the selection process.

In this work, Theoretical Analysis method and Delphi method are adopted for LCISS indicator selection.

- Theoretical Analysis method selects indicators based on the evaluator's own relevant professional knowledge level and his understanding of the definition and connotation of the target object.

- Delphi method is one of the most representative empirical methods, as well as one with more relative objectivity and scientific reasonability. It gathers data from respondents within their domain of expertise by developing two or more rounds of group communication which aims to make a convergence of opinion on a certain issue (Hsu and Sandford 2007). By applying the Delphi method, respondents make the judgment independently in order to avoid mutual influence. The judgment result will be analyzed and sent back to respondents as reference of the next round of judgment. At the end, the process is stopped at a pre-defined stop criterion (e.g. number of rounds) and the final judgment determines the result (Rowe and Wright 1999).

(3) Indicator selection steps and result analysis

① Indicator selection steps

After the structure of the indicator list is developed, and determined the principle and method of indicator selection, indicators are selected following the steps below.

a. Indicator database establishment

An indicator database is developed on the basis of summarizing numbers of widely approved and applied Chinese and international research results. It embodies 33 evaluation systems (Table 4.2) and 20 publications (Condon, Cavens et al. 2009, A. Wang 2010, Fu, Liu et al. 2010, Niu 2010, Shao and Ju 2010, Chu, Ju et al. 2011, Li and Xu 2011, Li and Yu 2011, Lu, Tian et al. 2011, Price, Zhou et al. 2011, Wang, Zhou et al. 2011, Xin 2011, Xiong 2011, Zhang, Chen et al. 2011, Zhou, Ohshita et al. 2011, Yang 2012, Zhou, He et al. 2012, Zhu and Liang 2012, Institute for Urban and Environmental Studies Chinese Academy of Social Sciences 2013, Williams 2014). Indicators from these results were classified into categories of urban design, transport, energy, building, water, and municipal solid waste. The overlapped indicators were excluded from the database.

Table 4.2 Referenced evaluation systems

Type	No.	Evaluation system	Publisher
International	1	Indicators of Sustainable Development (2007)	United Nations
	2	Indicators for Sustainable Development Goals	Sustainable Development Solutions Network
	3	G20 low carbon competitiveness index: 2012 update	Vivid Economics
	4	Global City Indicators Facility	Global City Institute
	5	European Green City Index	Siemens
	6	Urban Sustainability Indicators	European Foundation
	7	Sustainability Performance Indicators	Global Reporting Initiative
	8	Low Carbon Indicators Toolkit	Regions for Sustainable Change
	9	LEED Green Building Rating System-ND (2009)	The US Green Building Council – USGBC
	10	DGNB-New Urban District	German Sustainable Building Council
	11	Indicators of Development Sustainability	The World Bank
	12	Environmental Sustainability Index (2002)	Yale Center for Environmental Law and Policy, Yale University Center for International Earth Science Information Network, Columbia University
	13	Urban Indicators	United Nations Human Settlements Programme
	14	LCI®--Low Carbon Index®	Institute of City Planning and Urban Design, University of Duisburg-Essen

Chinese	1	Eco-Garden City Standard	Ministry of Housing and Urban-Rural Development
	2	National Landscape Garden City Standard	Ministry of Housing and Urban-Rural Development
	3	Evaluation Index on Green and Construction for Key Small Towns (Trial)	Ministry of Housing and Urban-Rural Development, Ministry of Finance and National Development and Reform Commission
	4	China Habitat Environment Prize (Trail)	Ministry of Housing and Urban-Rural Development
	5	China Eco-City Index System	Chinese Society for Urban Studies
	6	Ecological County, Eco-City, Eco-Province Construction Index (Trail)	Ministry of Environmental Protection
	7	Evaluation System for Low Carbon Industrial Development Zone	Institute for Sustainable Communities
	8	China Low Carbon City Evaluation Indicator System	Institute for Urban and Environment Studies, Chinese Academy of Social Sciences
	9	Urban Sustainability Index (2013)	Urban China Initiative
	10	Ecological Modernization Index	Chinese Academy of Sciences
	11	Low-Carbon City Evaluation Index System	China National Institute of Standardization
	12	Evaluation Standard for Green Transportation Demonstration City (Trial)	Ministry of Transport
	13	Indicator System for Tangshan Bay Eco-City	Tangshan
	14	Key Performance Indicators of the Sino-Singapore Tianjin Eco-City	Tianjin
	15	Shenzhen Guangming New District Green City Index System	Shenzhen
	16	Beijing Ecological Demonstration Area Evaluation Standard	Beijing
	17	Indicator System for Qingdao Sino-German Eco-park	Qingdao
	18	Indicator System for Guiyang Eco-Civilization City	Guiyang
	19	China Environmental	Yale Center for

Performance Index	Environmental Law and Policy, Yale University Center for International Earth Science Information Network, Columbia University Chinese Academy for Environmental Planning City University of Hong Kong

b. Primary Selection

In compliance with the selection principals of “relevant”, “independent”, “systematic”, and “measurable”, indicators from the database are analyzed, compared and aggregated during the process of primary selection. At the end of this step, 89 indicators are selected as a result.

c. Expert Questionnaire Survey (1st Round)

The 1st round questionnaire was conducted based on the results of primary selection (Appendix 9). This survey was conducted through various forms of network communication, interview, and academic seminar. Respondents included professionals from universities, scientific research institutions, government planning agencies, and authoritative international organizations. Recommendations of indicator selection, modification, and supplement were summed up and statistically analyzed. The 1st round survey altogether provided 36 questionnaires, of which 30 effective ones were collected.

d. Expert Questionnaire Survey (2nd Round)

The 2nd round questionnaire (Appendix 10) was actually a feedback of the 1st round survey. But unlike the 1st round questionnaire, recommendation of indicator modification and supplement was no longer required in this round in order to narrow the indicator list down. Judgment was only needed to make an indicator selection by respondents. The total of 30 questionnaires was issued, and 25 effective ones were reclaimed. The result of the 2nd round survey is shown in Appendix 11.

e. Experts’ Consultation

After two rounds of questionnaire survey, the final round optimization of indicator selection is in the form of experts’ consultation. The consultant group includes 10 experts from authorities, such as the China Academy of Urban Planning and Design (CAUPD), China Architecture Design & Research Group, Chinese Society for Urban

Studies, Sino-Singapore Tianjin Eco-City, and universities in China and Germany. After discussions, the indicator list of LCISS with 54 indicators has been finalized (Table 4.1). Details of indicator explanation, application condition, data source etc. will be discussed in 4.3.

② Results analysis of indicator selection

According to the results of the survey, most of the indicators with a selection rate of over 50% were generally assumed to retain in the indicator list of LCISS, while adjustment would be made in the process of experts' consultation.

a. Urban Design has 20 preliminary indicators in the questionnaire (Figure 4.3).

The indicator "existence of open green space" got the highest selection rate with 100 percent, of which 68% of experts suggested to interpret this indicator by using the parameter of "greenery coverage ratio", while the other 32% suggested using "open green space area per capita". Ultimately, "greenery coverage ratio" was selected in the system.

Some indicators were ruled out during the process of expert consultation; even they got a relatively high selection rate. For example, selection rates of "supplement of existing functions in the surrounding" and "employment-housing equilibrium index" were 76% and 92% respectively. However, their connotations and characterizations have overlapping relationship with another indicator "mixture of functions". Hence, only the indicator of "mixture of functions" was kept in the system. Another example is the indicator of "existence of water surfaces" with 60% selection rate, which was excluded from the indicator list as it is counted as a part of park green area in some cases in compliance with Chinese statistic systems, but not in other cases. This will make it difficult to get accurate data from it.

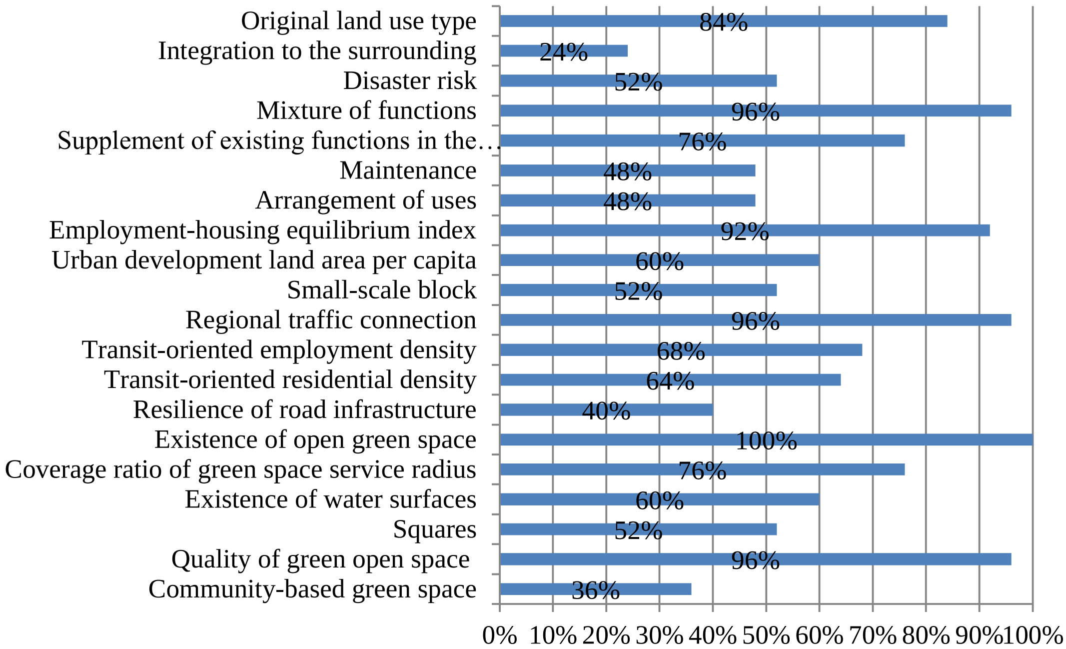

Figure 4.3 Selection rates of preliminary indicators of urban design

b. Transport has 33 preliminary indicators in the questionnaire (Figure 4.4).

The indicator of "connection to fast mass transport" is to evaluate the distance between area center and fast mass transport. It received a high selection rate of 84%. Nevertheless, after discussion, most experts agreed that this indicator is overlapped with indicators of "transit-oriented employment density" and "transit-oriented residential density". In order to guarantee the independence of indicators in LCISS, this indicator was eliminated.

The selection rates of indicators of "congestion of interior road network" and "congestion frequency fast public transport" were 68% and 56% respectively. These indicators aimed to evaluate and compare the speed of commuting by private car to public transport. Since it is difficult to collect this data, some experts suggested replacing them with the indicator "velocity of public transport".

The indicators of "city-accessibility-concept" and "differentiated area-toll" are to evaluate the incentives of promoting low-carbon vehicles. Their selection rates were 52% and 56% respectively. As suggested by some experts, replacing these indicators with one new indicator of "prioritization for low emission vehicles" could enable more adequate evaluation of a city's endeavor on low-carbon vehicle promotion.

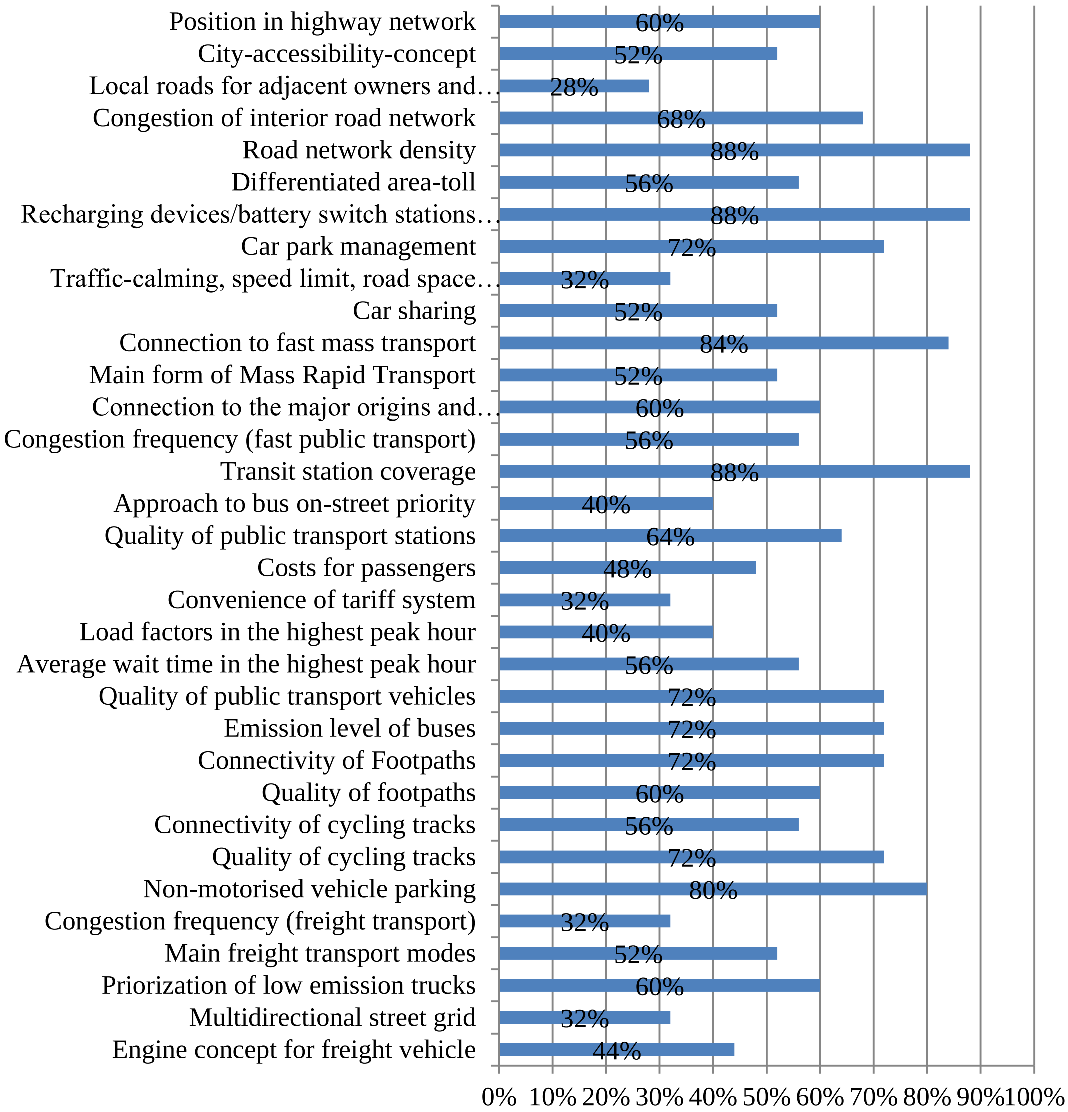

Figure 4.4 Selected rates of preliminary indicators of transport

c. Energy has 7 preliminary indicators in the questionnaire (Figure 4.5). All indicators had more than 50% selection rate. The indicator "renewable electricity use in buildings" got the selection rate of 88%, of which 52% experts suggested this indicator be interpreted by using the parameter of "renewable energy production". Ultimately, "renewable energy production" was selected in the system. During the experts' consultation, the indicator of "controllability of heating systems" was ruled out since the related data is not available, in addition, it has an overlapping relationship with the indicator of "metered heating rate".

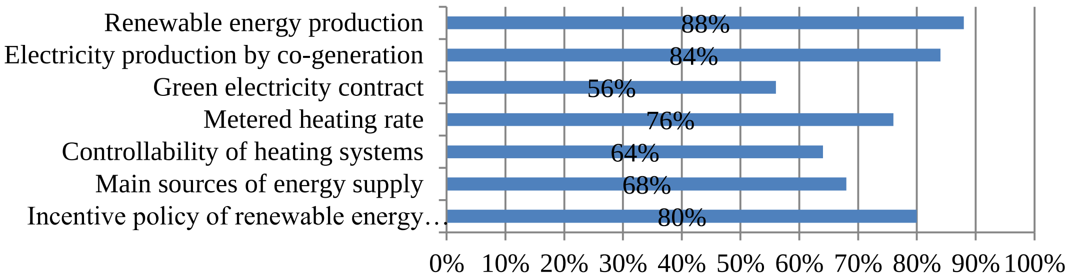

Figure 4.5 Selected rates of preliminary indicators of energy

d. Building has 18 preliminary indicators in the questionnaire (Figure 4.6). None of the indicators were kept in LCISS, most of them even received a high selection rate in the surveys. Since experts' consultation suggested to adopt existing authoritative building evaluation standards, such as National Evaluation Standard for Green Building (GB-T50378 2014), in order to improve the scientificity, comprehensiveness, and measurability of the evaluation. The final result of the building sector included four new indicators: "qualification ratio of building energy efficiency in new buildings", "proportion of green buildings in new buildings", and "qualification ratio of building energy efficiency in existing buildings".

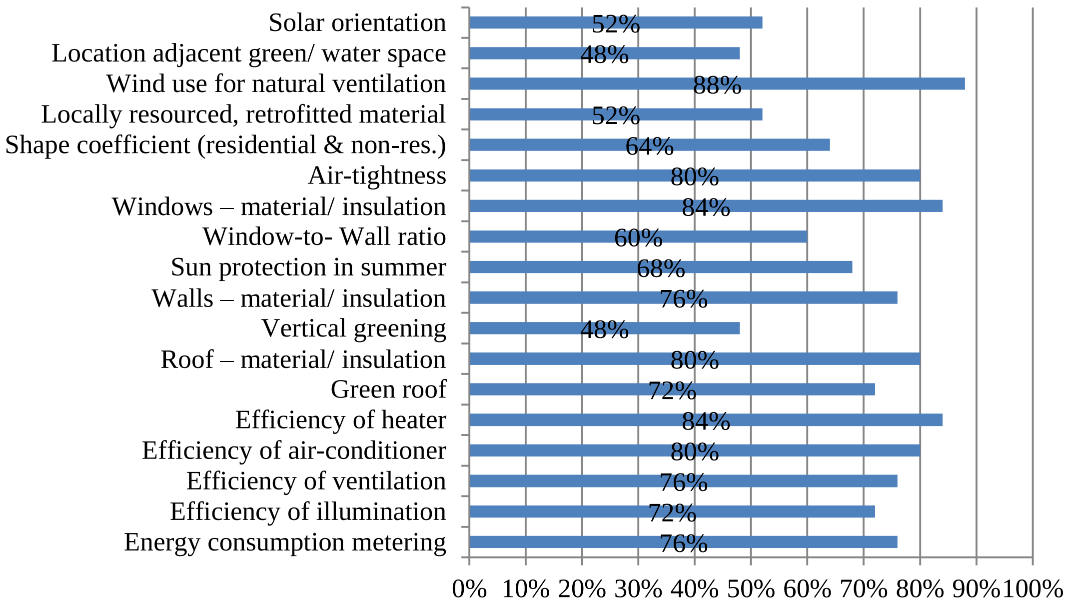

Figure 4.6 Selected rates of preliminary indicators of building

e. Water has 10 preliminary indicators in the questionnaire (Figure 4.7). Of which 8 indicators got a selection rate of above 50%. This result was well agreed by the experts' consultation.

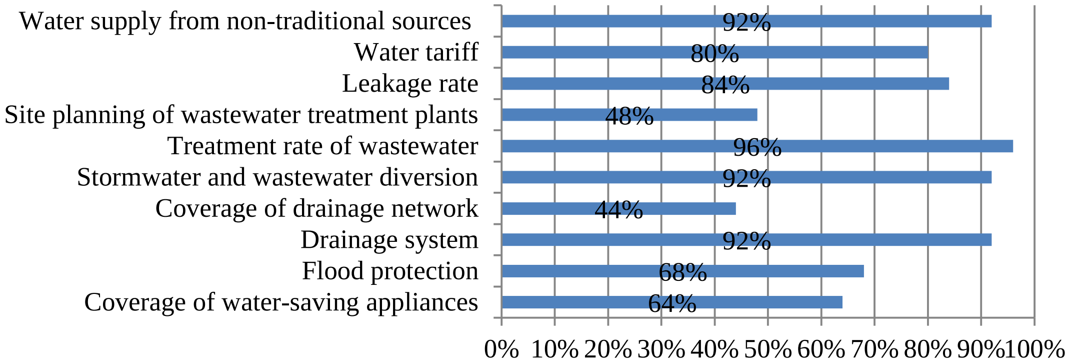

Figure 4.7 Selected rates of preliminary indicators of water

f. Municipal Solid Waste has 9 preliminary indicators in the questionnaire (Figure 4.8). Most indicators with high selection rate were approved by consultant experts, except the indicator of "waste recycling rate", because the data is unavailable in China. The waste recycling level could be indirectly reflected, to some degree, by the indicator of "landfilling rate".

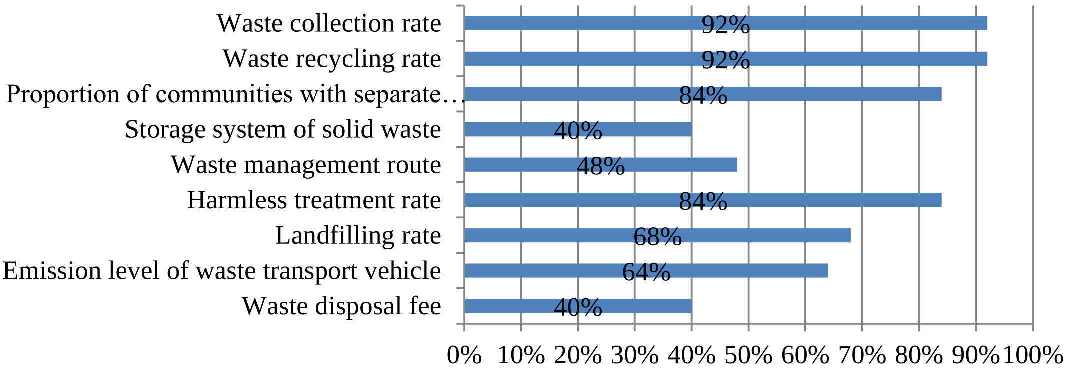

Figure 4.8 Selected rates of preliminary indicators of MSW

4.2.3 Types of indicator

LCISS indicators could be classified into two types: essential indicator, and expanded indicator.

Essential indicators are indispensable indicators of low-carbon city evaluation, which is closely related to urban development and construction. Additionally, essential indicators have universal applicability for cities with various natural environment, economic status, and social background. Thereby, they are binding indicators used in low-carbon city evaluation by LCISS.

Expanded indicators have certain perceptiveness that aim to guide a city's medium and long-term low-carbon development. They are the optimization indicators of LCISS putting forward higher requirements for the city's climate mitigability and adaptability.

Unlike the universal essential indicators, expanded indicators have certain applicable conditions and scopes. Whether or not to apply an expanded indicator to a city's evaluation is determined on the basis of the applicable condition and scope of the indicator and the actual situation of the city.

4.2.4 Values of indicator

LCISS is a comprehensive evaluation system with multi-indicators. It organizes a number of single indicators, each from a different direction to reflect a city's low-carbon level, in order to conduct an overall and systematic evaluation of low-carbon city. Since these indicators have different units of measurement, to formulate one comprehensive evaluation system requires a unitless score that can be added for performance metrics of all indicators, i.e. a normalization scale. In LCISS, normalization is performed with normalized scores between -2 and +2. In this linear scale, scores of +2 are given to the best performances, scores of -2 are given to the worst performances, scores of 0 are given to the average or standard performances, scores of +1 are given to performances between 0 and +2, and scores of -1 are given to performances between 0 and -2. The distance from 0 to +1 and +1 to +2 should be the same amount as the distance from 0 to -1 and -1 to -2. At last, using the normalized score and weight, the comprehensive evaluation value (see 4.2.6) as quantitative evaluation result will be calculated.

Another question is which performance should mark the upper score (+2) and which conversely should mark the lower score (-2). Basically, it should follow the following principles:

- The existing national or international standards should be consulted as much as possible;
- National relevant policies should be considered as important references, such as the national five-year plan;
- The current reality of cities in China should be taken into account;
- International advanced experiences should be learned selectively depending on its relevance;
- Delphi method could be applied, when there is no reliable and authoritative reference.

4.2.5 Weighting assignment

In the evaluation of low-carbon city, the relative important degree of each indicator is different from one another. Even for the same indicator, the relative important degree varies when the evaluation scale changes. To integrate this differentiation, a weight measurement framework is needed.

The Analytic Hierarchy Process (AHP)[22] method, developed in 1971 by Prof. Thomas L. Saaty of Pittsburg University, is a widely used scientific method for determining weight, especially for solving problems involving multi criteria analysis. Through AHP method, complex problems could be systemized. It firstly decomposes the decision problem into a hierarchical structure with more easily comprehended sub-problems. After the hierarchy is built, the comparison matrix is developed by using pairwise-comparison method based on a nine point weighting scale (Table 4.3), in order to determine user preferences. In accordance with the comparison matrix, the attribute values for each of the alternatives are calculated, and the consistency of the result is checked. In the final step, the overall composite weight of each alternative is computed. Using logic analyses and mathematic calculation, the AHP method can reduce impact from the experience and subjective awareness of decision-makers and increase the accuracy of decisions.

Table 4.3 1-9 Scale

Scale	Definition
1	i equally important to j
3	i moderately important to j
5	i strongly important to j
7	i very strong important to j
9	i extremely important to j
2,4,6,8	The intermediate state between the two determination
Reciprocal	If i compared to j, the determination is aij, then aij = 1/aij

Source: (Saaty 1977, Du 2013)

In LCISS, the AHP and Delphi methods are adopted to determine the weight of indicators of LCISS. It needs 5-10 local experts from the target cities of evaluation to take the independent scoring. The results will be formed into judgment matrices that will be calculated by the weighted geometric mean method to get the weight of each indicator.

Another point worth noting is that as discussed in 4.2.3, the indicator list contains the indispensable “essential indicators” and the relatively flexible “expanded indicators”. Accordingly, in the process of LCISS application, the specific indicator list of target city of evaluation should be formed before the weight assignment.

The steps of weight assignment are listed below:

(1) Weight of first-class indicators

[22] More information about AHP refer to http://en.wikipedia.org/wiki/Analytic_hierarchy_process

① Local experts will be organized to evaluate the various first-class indicators by comparing them to one another, and quantify the preference by using the nine point weighting scale, with respect to the goal of low-carbon city evaluation. An example is shown in Table 4.4. According to the result of this survey, a comparison matrix as illustrated in Table 4.5 could be constructed. In Table 4.5, a_{ij} denotes the comparative importance of indicator C_i with respect to indicator C_j, and aij=1/aji. For an example, see Figure 4.9.

Table 4.4 Pair-wise comparison based on 1-9 scale

	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Urban design								×										Transport
Urban design						×												Energy
Transport							×											Energy

Table 4.5 Comparison matrix

	C_1	C_2	C_3	…	C_j
C_1	a_{11}	a_{12}	a_{13}	…	a_{1j}
C_2	a_{21}	a_{22}	a_{23}	…	a_{2j}
C_3	a_{31}	a_{32}	a_{33}	…	a_{3j}
…	…	…	…	…	…
C_i	a_{i1}	a_{i2}	a_{i3}	…	a_{ij}

$$A = \begin{array}{c} \\ \text{Urban Design} \\ \text{Transport} \\ \text{Energy} \end{array} \begin{array}{c} \begin{array}{ccc} \text{Urban Design} & \text{Transport} & \text{Energy} \end{array} \\ \begin{bmatrix} 1 & 2 & 4 \\ \frac{1}{2} & 1 & 3 \\ \frac{1}{4} & \frac{1}{3} & 1 \end{bmatrix} \end{array}$$

Figure 4.9 Example of comparison matrix

② Calculate relative normalized weight W_j of each indicator by using the following formula:

$$W_j = \frac{1}{n}\sum_j^n \frac{a_{ij}}{\sum_{j=1}^n a_{ij}} \qquad i,j = 1,2,\ldots\ n. \tag{1}$$

③ Determine the consistency vector ν, maximum eigenvalue max λ, and calculate the consistency index CI:

$$v_i = \left(\sum_{j=1}^n w_j\, a_{ij}\right) w_i \qquad i,j = 1,2,\ldots\ n \tag{2}$$

$$\lambda = \frac{\sum_{i=1}^{n} v_i}{n} \qquad i = 1,2,\dots n. \tag{3}$$

$$CI = \frac{\lambda - n}{n-1} \tag{4}$$

④ Obtain the random index RI in Table 4.6, and calculate the consistency ratio CR by using the following formula (5). Judgment is appropriate when CR < 0.1.

$$CR = \frac{CI}{RI} \tag{5}$$

Table 4.6 Random index

Number of criteria	1	2	3	4	5	6	7	8	9
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

(2) Weight of second- and third-class indicators

After determining the weight W of first-class indicators, the normalized relative weight – B of second-class indicators with respect to the j-th first-class indicator are calculated following the same calculation procedure. The second-class indicators that are not related to the j-th indicator from the first-class are given the weight of 0.

The overall composite weight of second-class indicators S could be calculated in accordance with the formula below:

$$S_i = \sum_{j=1}^{r} W_j B_{ji} \qquad i = 1, 2, \dots n \tag{6}$$

The calculation of overall composite weight of third-class indicators is in the same way as that of the second-class indicators.

4.2.6 Comprehensive evaluation value

After the process of weight assignment, the comprehensive evaluation value of low-carbon city development could be calculated in accordance with the formula below:

$$F = \sum_{i=1}^{n} w_i \, x_i \tag{7}$$

In the formula (7), F represents the comprehensive evaluation value; n represents the number of evaluation indicators; w_i represents the composite weight of the i-th evaluation indicator; x_i represents the normalized evaluation score of the i-th evaluation indicator.

4.3 Indicator description of Low-Carbon Indicator System – Sino

4.3.1 Indicators of urban design

In LCISS, the urban design sector contains 4 second-class indicators and 11 third-class indicators (Appendix 12).

(1) Site Planning

① Original land use type

a. Interpretation:
Original land use type refers to land use type of the evaluation object before the construction.

Plants and soils can store CO_2, and this storage is named biological carbon sequestration (or carbon sink) (U. S. Fish & Wildlife Service 2014). Most land use changes have a significant impact on the amount of carbon stored in vegetation and soil, therefore either emission or sequestration of CO_2 occurs (Houghton and Goodale 2004). The unsustainable land use, such as disafforestation, grassland cultivation, has become the second largest source of greenhouse gas emissions following the burning of fossil fuels (Lai 2010). In order to realize low-carbon city development, transformation of land use that releases carbon into the atmosphere should be limited.

b. Evaluation scale: Scale 1, 2 and 3

c. Type: Essential

d. Data source: Urban construction department

e. Methodology:
Owing to different natural conditions and human activities, the carbon intensity of different types of land use varies from one another. In general, arable land (-0.37t/hm^2), woodland (-0.49t/hm^2) and grassland are important carbon sequestration that are characterized by low carbon intensity. Constructed land (55.8t/hm^2) is a land use type with high carbon intensity, within which industrial land (196t/hm^2) is the most carbon-intensive type that is much higher than commercial and residential land (8.3t/hm^2) (Lai 2009). A recent survey of 6 regions of China (Northern China, Northeast China, Eastern China, Central and South China, Southwest China and Northwest China) suggested that: i) conversion of arable land, woodland, and grass land to constructed land has a strong carbon emission effect (Figure 4.10-4.12); ii)

conversion of unused land to constructed land has a slight carbon sink effect (Figure 4.13); iii) conversion of constructed land to other land use types mostly has a carbon sink effect (Figure 4.14) (Zhang, Lai et al. 2013).

In the LCISS evaluation, the worst evaluation (-2) is received for the urban development on arable land, woodland and grassland. The standard evaluation (0) is given for the development on unused land, which has a slight effect on CO_2 emissions. The best evaluation (+2) is assigned if the brownfield[23] is utilized, because it benefits in mitigating the pressure on urban land demand and improving the urban environment, while it brings no carbon emission effect.

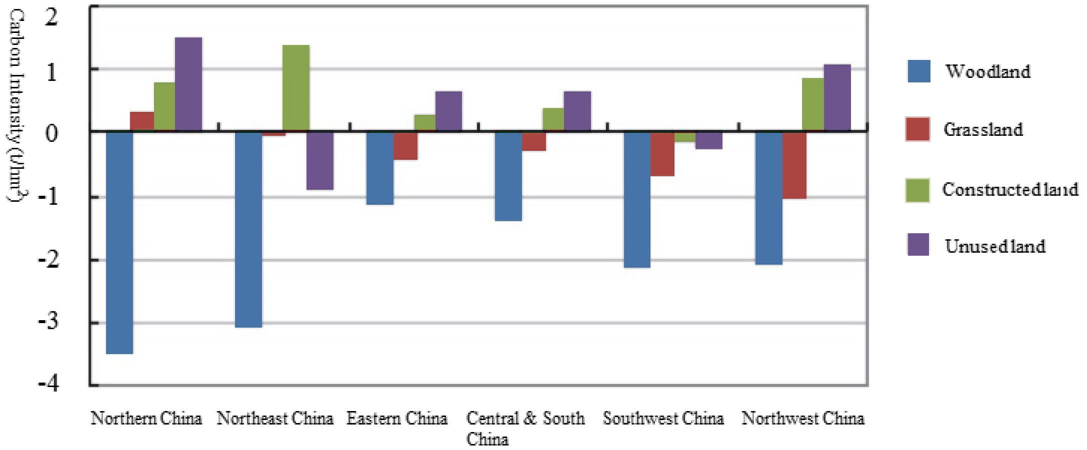

Figure 4.10 Carbon emission intensities due to the transfer out of arable land
Source: (Zhang, Lai et al. 2013)

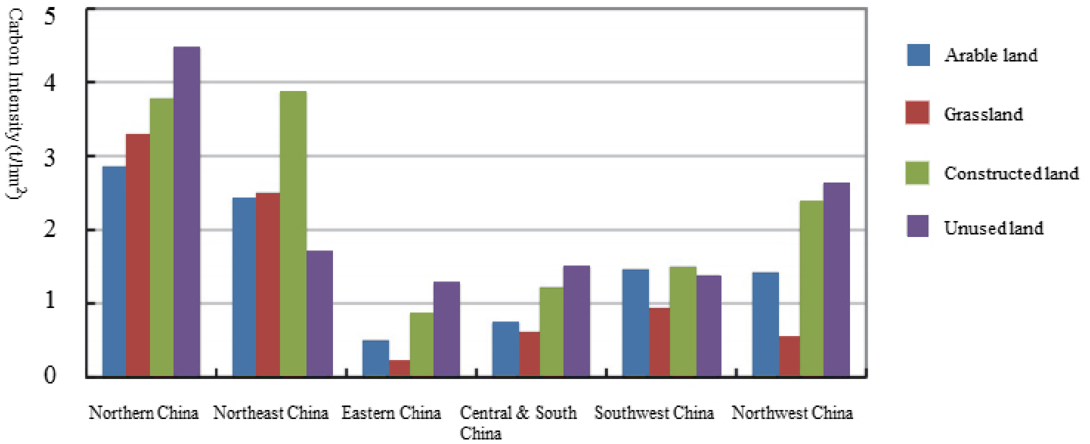

Figure 4.11 Carbon emission intensities due to the transfer out of woodland
Source: (Zhang, Lai et al. 2013)

[23] The Environmental Protection Agency (EPA) defines the "brownfield" as abandoned, idled, or under-used industrial and commercial facilities where expansion or redevelopment is complicated by real or perceived environmental contamination.

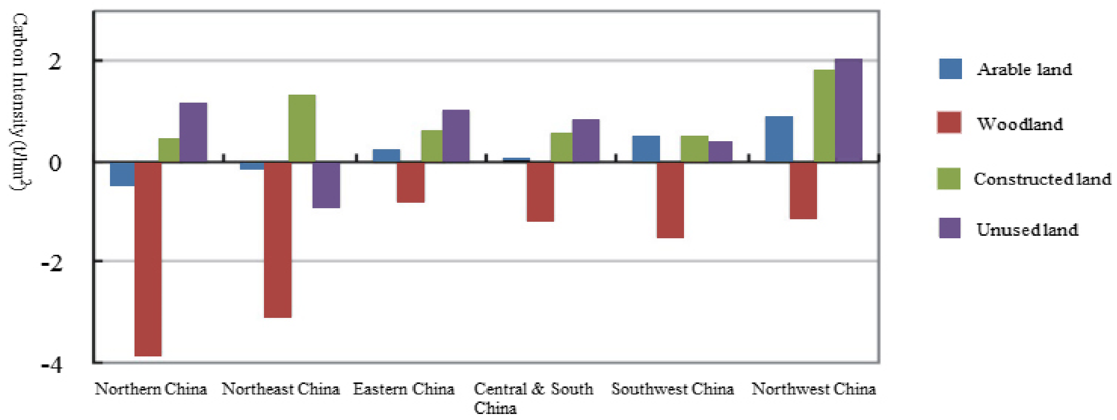

Figure 4.12 Carbon emission intensities due to the transfer out of grassland
Source: (Zhang, Lai et al. 2013)

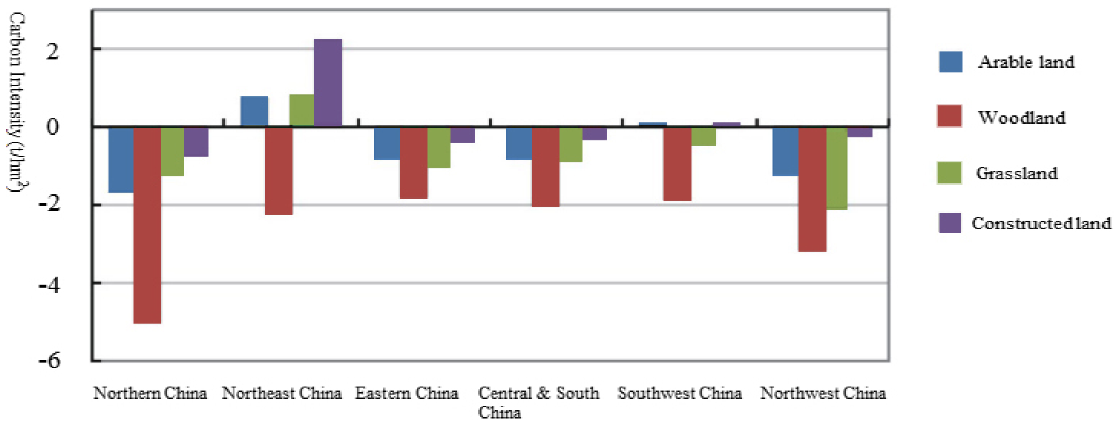

Figure 4.13 Carbon emission intensities due to the transfer out of unused land
Source: (Zhang, Lai et al. 2013)

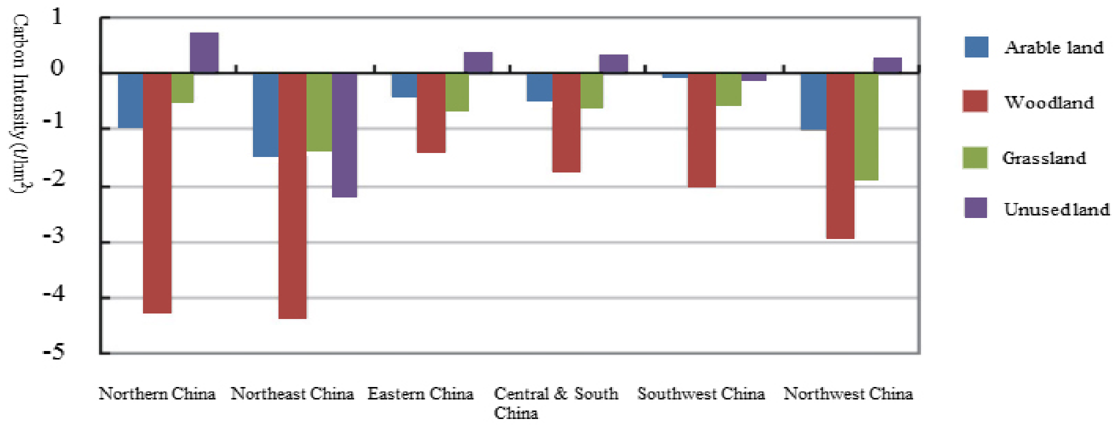

Figure 4.14 Carbon emission intensities due to the transfer out of constructed land
Source: (Zhang, Lai et al. 2013)

② Disaster risk

a. Interpretation:

Disaster risk is an indicator evaluating if there is construction in areas that are threatened by disasters, such as flood, geologic hazard, and secondary disaster in the evaluation object.

The adverse effects of climate change may enlarge the scope of potential development-forbidden and -restricted areas. Thus, in the process of assessment of land use suitability, special attention should be given to the climatic impact on land use suitability, in order to identify the unsafe areas, and to ensure that no constructed land is in the areas at high risk of climate hazard (e.g. rising sea-levels, flooding, landslides or any other risk). This is essential for disaster prevention under climate change context.

b. Evaluation scale: Scale 1 and 2

c. Type: Essential

d. Data source: Land management department

e. Methodology:
According to the assessment report of land use suitability, evaluation objects that have no construction in high-risk areas get a high evaluation (+2); objects completely or partially developed in areas affected by climate hazard get an evaluation of -2.

(2) Land Use

① Mixture of functions

a. Interpretation:
Mixture of functions refers to diversity index of land use.

A healthy mix of land use enables various forms of land use (such as residential houses, offices, shops, public services, etc.) to be co-located in an integrated way. It can decrease the distance and number of automobile trips, so as to reduce the associated energy consumption and carbon emissions.

In the evaluation of mixture of land use, two evaluation schemes are provided. Scheme 1 is applicable to evaluation objects larger than 2 km^2, and scheme 2 is applicable to objects less than 2 km^2.

b. Evaluation scale: Scale 1, 2 and 3

c. Type: Essential

d. Data source: Urban construction department

e. Methodology:

Scheme 1:
Simpson's diversity index is suggested for the evaluation. The greater the index value implies the more diverse the land use. The formula is as follows:

$$D = 1\text{-}\sum\left(\frac{1}{N}\right)^2$$

In formula (1), D represents the Simpson's diversity index; N represents the number of land use types.

In this evaluation, land use types take reference of the 35 classes of the "Code for classification of urban land use and planning standards of development land (GB50137-2011)" (Ministry of Housing and Urban-Rural Development of the People's Republic of China 2012), which contains 8 categories, 35 classes, and 42 small classes. A precondition of evaluation is no less than 4 categories are covered.

In LCISS, objects with less than 7 types of land use ($D<0.980$) receive -2 points; objects with 7-9 types of land use ($0.980 \leq D \leq 0.988$) receive an evaluation of -1; objects with 10 types mixed land use ($D=0.990$) receive a standard evaluation (0); objects with 11-13 types mixed use ($0.992 \leq D \leq 0.994$) receive an evaluation of +1; evaluation objects with no less than 14 types mixed use ($D \geq 0.995$) receive the best evaluation of +2.

Scheme 2:
In this evaluation, types of land use take reference of Leadership in Energy and Environmental Design (LEED) for Neighbourhood Development that includes 20 uses. The evaluation has to be used with the following qualifications: i) if two different uses appear in one public building, only one use can be taken into the calculation; ii) in a mixed-use building, all kinds of uses should be calculated, but no more than half of uses can appear in one building; iii) certain use can be calculated not more than two times in the same area.

Evaluation objects with no more than 3 uses are given the worst evaluation of -2; objects with 4-8 uses receive -1 point; objects with 9-13 uses receive the standard evaluation (0); objects with 14-18 uses receive the evaluation of +1; objects with not less than 19 uses, or objects with more than 13 uses while the employment-housing equilibrium index[24] is over 50%, are given the best evaluation of +2.

② Urban development land area per capita

a. Interpretation:

[24] employment-housing equilibrium index = (employable residents in the city that are employed in the city / employable residents in the city) *100%

Urban development land includes land for urban residence, land for public administration and services, land for business and commercial facilities, industrial and manufacturing land. Its scale is the sum of all above lands, unit in hm^2. *Urban development land area per capita* refers to urban development land area divided by quantity of residential population within the scope, in m^2/person (Ministry of Housing and Urban-Rural Development of the People's Republic of China 2012).

The control of urban development land is crucial for the development of low-carbon city. With China's accelerating urbanization process, most cities, especially mega-cities, are expanding quickly and inevitably experience urban sprawl. As the opposite of compact urban form, it increases the energy consumption and carbon emissions from the sectors of transport and infrastructure operation (see 3.1.4). Moreover, since a large number of arable land, woodland, and grassland are transformed into urban development land, carbon sinks are severely damaged.

b. Evaluation scale: Scale 2 and 3

c. Type: Essential

d. Data source: Urban construction department

e. Methodology:

In the Chinese national standard "City Land Classification and Land Use Planning and Construction Standards (GB 50137-2011)" (Table 4.7), planning standard of urban development land per capita is determined based on a city's current status of urban development land per capita, climate zone[25], and population size. In the evaluation of LCISS, according to this standard, the best evaluation of +2 is granted when the urban development land area per capita is lower than the planning standard; the standard evaluation of 0 is granted when the urban development land area per capita is in compliance with the planning standard; an evaluation of -2 is given when urban development land area per capita is higher than the planning standard.

Table 4.7 Planning standard of urban development land per capita (m^2 per capita)

Climate zone	Current status of urban development land per capita	Planning standard of urban development per capita	Adjustment range		
			Planning population size ≤2 million people	Planning population size 2.01 ~ 5 million people	Planning population size >5 million people
Ⅰ, Ⅱ, Ⅵ, Ⅶ	≤65.0	65.0 ~ 85.0	>0.0	>0.0	>0.0
	65.1 ~ 75.0	65.0 ~ 95.0	+0.1 ~	+0.1 ~	+0.1 ~

[25] The division of climate zone takes reference of the Chinese national standard "Building Climate Zoning Standards (GB50178-93)".

			+20.0	+20.0	+20.0
	75.1 ~ 85.0	75.0 ~ 105.0	+0.1 ~ +20.0	+0.1 ~ +20.0	+0.1 ~ +15.0
	85.1 ~ 95.0	80.0 ~ 110.0	+0.1 ~ +20.0	-5.0 ~ +20.0	-5.0 ~ +15.0
	95.1 ~ 105.0	90.0 ~ 110.0	-5.0 ~ +15.0	-10.0 ~ +15.0	-10.0 ~ +10.0
	105.1 ~ 115.0	95.0 ~ 110.0	-10.0 ~ -0.1	-15.0 ~ -0.1	-20.0 ~ -0.1
	>115.0	≤115.0	<0.0	<0.0	<0.0
Ⅲ, Ⅳ, Ⅴ	≤65.0	65.0 ~ 85.0	>0.0	>0.0	>0.0
	65.1 ~ 75.0	65.0 ~ 95.0	+0.1 ~ +20.0	+0.1 ~ +20.0	+0.1 ~ +20.0
	75.1 ~ 85.0	75.0 ~ 100.0	-0.5 ~ +20.0	-5.0 ~ +20.0	-5.0 ~ +15.0
	85.1 ~ 95.0	80.0 ~ 105.0	-10.0 ~ +15.0	-10.0 ~ +15.0	-10.0 ~ +10.0
	95.1 ~ 105.0	85.0 ~ 105.0	-15.0 ~ +10.0	-15.0 ~ +10.0	-15.0 ~ +5.0
	105.1 ~ 115.0	90.0 ~ 110.0	-20.0 ~ -0.1	-20.0 ~ -0.1	-25.0 ~ -5.0
	>115.0	≤110.0	<0.0	<0.0	<0.0

Note: Above standard shall not apply to new city (town) and capital. The planning standard of urban development per capita of new city (town) is 85.1 ~ 105.0 m^2 per capita. The planning standard of urban development per capita of capital is 105.1 ~ 115.0 m^2 per capita.

Source: (Ministry of Housing and Urban-Rural Development of the People's Republic of China 2012)

③ Small-scale block

a. Interpretation:

Small-scale block refers to the percentage of small-scale building block of all blocks. A block is the area for buildings within the street pattern of a city, and forms a basic unit of a city's urban fabric and residential area. A recent survey of 90 cities (28 in North America, 5 in South America, 45 in Europe, 6 in Asia, 5 in Australia, and 1 in Africa) suggested that a reasonable block scale should be controlled within 200m, considering the actual situation of Chinese cities, the suitable block scale in China is within the range of 150-200m (Huang and Sun 2012). Thus, small-scale block in LCISS is a block with a side length of 150-200m.

Along with China's current urban land expansion mode, the block scale in Chinese cities tends to become larger. This expansion of large-scale model brings a range of urban problems. Large-scale blocks make people lose interest in walking and cycling, and also keep public transport off the block, which partly encourages people to use private cars. Furthermore, great deals of traffic flows from the exits of blocks converging at main roads at peak hours will cause traffic congestion, and more energy consumption and more CO_2 emissions.

b. Evaluation scale: Scale 2 and 3

c. Type: Essential

d. Data source: Urban construction department

e. Methodology:
In this evaluation, the related indicator in "Beijing Ecological Demonstration Area Evaluation Standard" is consulted. Objects with less than 40% small-scale blocks are evaluated with -2; objects with 40% or more but less than 50% of small-scale blocks are evaluated with -1; objects with 50% or more but less than 70% of small-scale blocks are granted the standard evaluation of 0; objects with 70% or more but less than 80% of small-scale blocks are evaluated with +1; the best evaluation (+2) is granted to the objects with over 80% of small-scale blocks.

(3) Accessibility

① Regional traffic connection

a. Interpretation:
Regional traffic connection is an indicator reflecting the evaluation object's accessibility. The attractiveness of areas increases with their accessibility (Baltes and Schmidt 2010). The more options available for transportation connection, the better accessibility is. Within which, it is ideal if more means of public transport are available, as it can significantly reduce the need to travel by private car. This could help to cut carbon emissions since public transport is, in most cases, much more energy efficient and thus will have less energy consumption and CO_2 emissions per kilometer traveled.

b. Evaluation scale: Scale 1, 2 and 3

c. Type: Essential

d. Data source: Urban construction department, transportation department

e. Methodology:
Evaluation objects that have no transportation connection are evaluated with -2; objects that have transportation connection but not covering the whole area receive -1 point; objects that have whole-area transportation connection but only by individual transport receive an evaluation of 0; objects that have whole-area transportation connection by individual transport and one type of public transport receive an evaluation of +1; objects that have whole-area transportation connection by individual transport and various types of public transport receive +2 points.

② Transit-oriented employment density

a. Interpretation:

Transit-oriented employment density is an indicator that compares employments per km^2 within 500m of public transport hubs with the average level of the whole area.

The distance between working and living places can considerably influence residents' commuting space-time distribution, mode, and other behaviors, thereby affecting the carbon emissions from transportation. Long-distance commutes can cause traffic congestion, and increase the air pollution and carbon emissions. Smart land use planning should generally aim at promoting job-housing balance, which can moderate the demand on transport systems by putting work and home closer together. Along with economy advancing and housing marketization processing in China, home-work separation has become a trend of most Chinese cities. Although this trend is gradually obvious, the job-housing spatial relationships could still be improved in some ways, such as the aforementioned mixed land use and small-scale blocks. One effective way is to promote spatial coupling between work/housing places and public transport hubs, i.e. enhance the employment and residential density around public transport stations. This could encourage people to commute with public transport, which is much more environmentally- and climate-friendly than private cars.

b. Evaluation scale: Scale 2 and 3

c. Type: Essential

d. Data source: Statistics department, urban construction department

e. Methodology:

The worst evaluation (-2) is assigned if the lowest employment density appears near the public transport hubs; whereas the best evaluation of +2 is granted if the highest employment density appears near the public transport hubs; standard evaluation of 0 is given when employment density at public transport hubs is in-line with the average density; if employment density at public transport hubs is slightly below the average level it receives an evaluation of -1; where employment density at public transport hubs is slightly above the average level it receives +1.

③ Transit-oriented residential density

a. Interpretation:

Transit-oriented residential density is an indicator that compares floor area ratio (FAR)[26] of residential land within 500m of public transport hubs with the average level. The calculation formula of FAR of residential land is as follows:

[26] Floor area ratio (FAR) is a building's total floor area divided by the size of the land which the building is located on.

FAR of residential = residential gross floor area / residential land area

b. Evaluation scale: Scale 2 and 3

c. Type: Essential

d. Data source: Statistics department, urban construction department

e. Methodology:
The worst evaluation of -2 is granted if the lowest residential density appears near the public transport hubs; whereas the best evaluation of +2 is granted if the highest residential density appears near the public transport hubs; standard evaluation of 0 is given when residential density at public transport hubs is in-line with the average density; if residential density at public transport hubs is slightly below the average it will receive an evaluation of -1; if residential density at public transport hubs is slightly above the average it receives +1.

(4) Green open space

① Greenery coverage ratio

a. Interpretation:
Green coverage ratio refers to the percentage of total urban area covered by the vertical projection of green plants, including trees, shrubs, lawns etc. The formula is as follows:

Greenery coverage ratio = (green plants in the vertical projection area / total urban area) * 100%

Green coverage ratio is an important indicator of urban environment quality evaluation, which reflects the greening effect of green spaces in cities. Green spaces with good greening effect can reduce energy consumption for cooling purposes by lowering high temperature in summer days, and make non-motorized transport more attractive by maintaining comfortable temperature for pedestrians and cyclists.

b. Evaluation scale: Scale 2 and 3

c. Type: Essential

d. Data source: Landscape and forestry department, urban construction department, statistics department

e. Methodology:
It is widely considered that the urban environment is good when its green coverage is over 50%. In China, most cities, especially large and middle-sized cities, cannot

achieve this level. Statistics show that the national greenery coverage ratio of built districts is 39.59% by 2012 (Ministry of Housing and Urban-Rural Development of the People's Republic of China 2013). In this evaluation, +2 is granted when the green coverage ratio is more than 20% above the average level; +1 is given when the green coverage ratio is higher than the average level but not over 20%; standard evaluation of 0 is given when the green coverage ratio is similar to the average level; -1 is assigned when the green coverage ratio is below the average level but not more than 20%; -2 is given when the green coverage ratio is more than 20% below the average level.

② Coverage ratio of park green space service radius

a. Interpretation:
Coverage ratio of park green space service radius refers to the proportion of residential areas that have access to park green space with an area of over 1000km^2 within the service radius of 500m. The formula is as follows:

Coverage ratio of park green space service radius = (residential land area access to park green space larger than 1000km^2 within the service radius of 500m/ total residential area) * 100%

The coverage ratio of park green space service radius is an important indicator reflecting the distribution of green space in a city. In the construction of an urban green space system, the distribution of green space has significant impact on the greening effect of green space (Suo 1999). By providing green space within a walking distance, more people could be invited to use the green space, thereby improving the usage rate of green space. Moreover, green spaces and gardens contribute greatly to improving the microclimate in the city. This could help relieve the 'urban heat island effect' in overcrowded cities, thus in summer time less cooling is necessary in buildings.

b. Evaluation scale: Scale 2 and 3

c. Type: Essential

d. Data source: Landscape and forestry department, urban construction department

e. Methodology:
In LCISS, evaluation of coverage ratio of park green space service radius takes reference from the “National Garden City Standard” (Ministry of Housing and Urban-Rural Development of the People's Republic of China 2005). -2 is evaluated when the coverage ratio of park green space service radius is less than 60%; -1 is evaluated when the coverage ratio is 60% or more but less than 70%; standard evaluation is given when the coverage ratio is 70% or more but less than 80%; +1 is given when coverage ratio is 80% or more but less than 90%; the best evaluation of +2 is granted when the coverage ratio is 90% or more.

③ Quality of green open space

a. Interpretation:

The *quality of green open space* could highly influence the safety, comfort, and accessibility of green open space, thus determines its usage rate. In addition, high-quality green open space could adjust microclimate and provide green shades, which reduce energy consumption for cooling purposes by lowering high temperatures on summer days. Moreover, it also serves as a crucial carbon sink and emergency shelter within a city.

b. Evaluation scale: Scale 3

c. Type: Expanded

d. Applicable condition and scope:

"Quality of green open space" is an optimization indicator. It is suggested to be applied when the essential indicators "greenery coverage ratio" and "coverage ratio of park green space service radius" receive standard evaluation (0) or above. Since one or a few well-developed green open space alone cannot promise a low-carbon green space system, without good greenery coverage and rational green open space distribution.

e. Data source: Landscape and forestry department, field study

f. Methodology:

The evaluation of quality of green open space includes seven criteria: i) equipped with various public facilities (e.g. furniture, sculpture, landscape decoration, and fountain); ii) plant low water consumption native plants; iii) well functional organized space with different uses; iv) good accessibility; v) bright lights at key locations; vi) clear signage; vii) Well shadowed; viii) Applied devices by renewable energy; ix) Applied light colored, durable, environmentally-friendly pavement material. Evaluation objects in which most green open spaces fulfill all criteria get the best evaluation of +2; no criterion fulfilled receive -2 points; most green open spaces fulfill 1-2 criteria get an evaluation of -1; most green open spaces fulfill 3-4 criteria get the standard evaluation of 0; most green open spaces fulfill 5-6 criteria receive the evaluation of +1.

4.3.2 Indicators of transport

In LCISS, the transport sector contains 4 second-class indicators and 21 third-class indicators (Appendix 12).

(1) Motorized individual transport

① Position in highway network

a. Interpretation:
Position in highway network is an indicator evaluating the connection of the evaluation objects to the surrounding highway network. It is ideal that a tangential connection of the area into the main highway network, whereby the source and target traffic should park on the edge of the center of the area.

b. Evaluation scale: Scale 1

c. Type: Essential

d. Data source: Transport department

e. Methodology:
The evaluation of coverage ratio of park green space service radius takes reference of the LCI®. The best evaluation (+2) is granted when the evaluation objects have highway inside the area or along a border; +1 is evaluated when the next highway is less than 1 kilometer away from the object's border; 0 is evaluated when the next highway is less than 2 kilometers away from the object's border; -1 is evaluated when the next highway is less than 5 kilometers away from the object's border; -2 is given when the next highway is 5 kilometers or more away.

② Road network density

a. Interpretation:
Density of the road grid refers to road length per unit of area, unit in km/km^2.

Dense road networks could, on one hand, improve the accessibility and service of road network. In a low-density road network, traffic flows mainly concentrate on few main roads, and cause traffic congestion. On the other hand, higher density of road network will increase the number of intersections and traffic lights, which might lower the driving speed of vehicles. This can effectively curb the usage of automobiles.

b. Evaluation scale: Scale 2

c. Type: Essential

d. Data source: Transport department, statistic department

e. Methodology:
The evaluation of road network density takes reference from "Code for transport planning on urban road (GB50220—95)" or local standard of evaluation objects when it is available. An evaluation of +2 is granted when the density of the road network is above the standard, and branch roads account for a higher proportion of the total length of the network; +1 is assigned when the density of road network is above the standard;

0 is given when the road network density complies with standard; -1 is evaluated when the density of road networks is below the standard; -2 is evaluated when the density of road network is below the standard, and branch roads account for a lower proportion of total length of network.

③ Car park management

a. Interpretation:
Car park management is an indicator evaluating the perfection of a city's car park management, which involves a series of factors, such as parking charges, availability, facilities, etc. International experience suggests that car park management within a city can affect the relative price and convenience of car driving (Dalkmann and Brannigan 2007), thus a smart car park management system can greatly reduce the level of car ownership and use.

b. Evaluation scale: Scale 3

c. Type: Essential

d. Data source: Transport department

e. Methodology:
The evaluation of car park management takes reference from "Evaluation Standard for Green Transportation Demonstration City (Trial)" (Ministry of Transport of the People's Republic of China 2002). Evaluation of +2 is granted when car park related local laws and regulations have been issued and implemented with clear responsibilities and appropriate management measures; Evaluation of 0 is given when car park related local laws and regulations are under way to develop; Evaluation of -2 is given when there is no car park related local law and regulation.

④ Recharging devices of E-mobility

a. Interpretation:
Recharging devices of E-mobility is an indicator evaluating the availability of recharging devices and battery switch stations.

Compared with traditional vehicles, electric cars are more fuel-efficient that could cut CO_2 emissions from transport without having to achieve a dramatic reduction in the number of vehicles. In order to facilitate the use of electric cars, integrated charging solutions need to be developed.

b. Evaluation scale: Scale 3

c. Type: Expanded

d. Applicable condition and scope:
This is an optimization indicator. Considering the actual social and economic foundation, it is suggested to be applied in big cities (urban population ≥ 1 million)[27]. At the moment, applying this indicator in middle- and small-sized cities is less feasible.

e. Data source: Transport department

f. Methodology:
This evaluation takes reference of the LCI®. The best evaluation of +2 is granted when there are adequate numbers of parks with recharging devices with access for all with easy payment and combined with a transport connection point. An evaluation of +1 is assigned when there are adequate numbers of parks with recharging devices with access for all with easy payment. The standard evaluation (0) is evaluated when there are some parks with recharging devices with access for all. -1 is given when there are some parks with recharging devices which access only for employees of some companies, private garage owners, or parking pass holders. The worst evaluation of -2 is given when there is no recharging device.

⑤ Car-sharing

a. Interpretation:
Car-sharing refers to the joint ownership of a vehicle, in which people have the right to use the vehicle, but not the ownership. It is actually a kind of convenient car rental.

Since many people are sharing a car, it can help to curb the rapid growth of private vehicle ownership, thus reducing carbon emissions and easing traffic congestion and parking pressures of the city.

b. Evaluation scale: Scale 3

c. Type: Expanded

d. Applicable condition and scope:
"Car-sharing" is an optimization indicator. Considering the actual social and economic foundation, it is suggested to be applied in big cities. At the present stage, applying this indicator in middle- and small-sized cities is less feasible.

e. Data source: Statistic Department

f. Methodology:

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[27] In accordance with the "Notice of the State Council on Adjusting the Standards for Categorizing City Sizes (No. 51 [2014] of the State Council)", cities are classified into six different scales of megacity behemoth (urban population ≥ 10 million), mega city (urban population 5-10 million), large city (urban population of 1-5 million), medium-sized city (urban population of 0.5-1 million), small city (urban population of 0.1-0.5 million), and small town (urban population < 0.1 million).

The evaluation of car-sharing includes five criteria: i) cars available in the whole area - not station-bounded; ii) easy registration and payment; iii) online reservation; iv) discount on public transport tickets; v) various types of vehicles (cars and trucks). Evaluation objects which fulfill 4 or more criteria receive +2 points; 2-3 criteria fulfilled get an evaluation of +1; 1 criterion fulfilled receive standard evaluation (0); an evaluation of -1 is given when car-sharing is available but no criterion fulfilled; objects with no car-sharing concept receive -2 points.

⑥ Prioritization for low emission vehicles

a. Interpretation:

Prioritization for low emission vehicles[28] is an indicator evaluating the incentives promoting the use of low emission vehicles.

The use of high energy-efficient vehicles can reduce the energy consumption and associated CO_2 emissions of vehicles per unit of travel. The establishment of a series of policies and incentives promoting the use of low emission vehicles could provide better guidance to the public behavior and consumption custom, thereby, offering a “turning point” for the development of low-carbon transport systems.

b. Evaluation scale: Scale 3

c. Type: Expanded

d. Applicable condition and scope:

This is an optimization indicator. Considering the actual social and economic foundation, it is suggested to be applied in big cities. At the present stage, applying this indicator in middle- and small-sized cities is less feasible.

e. Data source: Transport department

f. Methodology:

In the evaluation of “prioritization for low emission vehicles”, four criteria are involved: i) subsidies and tax concessions to encourage the purchase and use of low emission vehicles; ii) permission to enter auto restricted zones; iii) no traffic restrictions (odd-and-even number limit lines); iv) parking charge discount. Evaluation objects which fulfill all criteria get +2 points; 3 criteria fulfilled receives an evaluation of +1; 2 criterion fulfilled is evaluated at 0; 1 criterion fulfilled gets -1; the worst evaluation of -2 is given when no criterion are fulfilled.

(2) Public transport

[28] Low emission vehicle refers to new energy vehicle or vehicle that limit emissions to the National Discharge Standard of Vehicle Pollutant (Ⅴ Stage).

① Main form of Mass Rapid Transit (MRT)

a. Interpretation:
Mass Rapid Transit (MRT), as a passenger transportation service, usually refers to relatively high speed and capacity transit forms, carrying at least 5000 passengers per direction per hour at an operational speed of 20 kilometers per hour or above (Mehndiratta and Salzberg 2012). The choice of which form of MRT to use determines the service level and CO_2 emissions of a city's transport system, and it affects even the future development of the city.

The typical forms of MRT include: metro, bus rapid transit (BRT), light rail transit (LRT), and commuter rail system. Among them, metro is by far the fastest mode that operates at an average operational speed of 40-50 kilometers per hour. BRT and LRT systems are relatively slow with average speeds of 20-30 kilometers per hour. Commuter rail is a passenger rail transport service that operates within urban areas, or between urban areas and their outer suburbs, which operates at speeds varying from 50-200 kilometers per hour.

b. Evaluation scale: Scale 1

c. Type: Expanded

d. Applicable condition and scope:
Since the development of MRT is to meet big cities' requirement of carrying large numbers of passengers rapidly, which requires a threshold density of 5000 – 10000 people/km^2, this indicator is suggested to be applied in cities that meet this requirement.

e. Data source: Transport department, urban construction department

f. Methodology:
In this evaluation, the worst evaluation of -2 is given when there is no public transport at all; -1 is evaluated when there is only bus connection, no MRT; an evaluation of 0 is assigned when the main form of MRT is LRT/BRT; +1 is evaluated when the main forms of MRT include metro and LRT/BRT; the best evaluation (+2) is granted when the main forms of MRT include metro, LRT/BRT, and commuter rail.

② Connection to the major origins and destinations

a. Interpretation:
Connection to the major origins and destinations is an indicator evaluating the connectivity and connection mode between major origins and destinations in a city.

The areas serving the highest customer demand, such as workplaces, residential areas, universities and schools, shopping areas, and hospitals, are always the major origins and destinations of a city. In order to minimize travel distances and travel times for the majority of the population, corridors should connect as many origins and destinations as possible. This determines the accessibility of the public transport system, and directly influences people's traffic mode choices.

b. Evaluation scale: Scale 2

c. Type: Expanded

d. Applicable condition and scope:
Compared with middle- and small-sized cities, big cities have more origins and destinations with complex distribution; they also have a higher requirement of speed and capacity of public transport. Therefore, this indicator is suggested to be applied in big cities.

e. Data source: Transport department

f. Methodology:
In this evaluation, -2 is given when there is no connection to the major origins and destinations, or only bus connection to some of the major origins and destinations; -1 is given when there is a bus connection to most of the major origins and destinations; the standard evaluation of 0 is given when there is a bus connection to all major origins and destinations; an evaluation of +1 is granted when there is MRT connection to most of the major origins and destinations and a bus connection to the remaining origins and destinations; the best evaluation of +2 is granted when there is MRT connection to all major origins and destinations.

③ Transit station coverage rate

a. Interpretation:
Transit station coverage rate refers to the proportion of total urban area or city center area accessing the transit station within a distance of 500 meters. The formula is as follows:

Transit station coverage rate = (areas access to transit station within a distance of 500 meters / total urban area or city center area) * 100%

Quality of access to public transport can be rated by the average walking distance to the next transit station. Considering the comfort requirements and on availability of alternative, a distance within 500m will be acceptable. Reasonable transit station coverage can significantly enhance the attractiveness of public transport, thus reduce the car use.

b. Evaluation scale: Scale 2

c. Type: Essential

d. Data source: Transport department, urban construction department

e. Methodology:
The evaluation of transit station coverage takes reference of "Beijing Ecological Demonstration Area Evaluation Standard". An evaluation of -2 is given when the transit station coverage rate is less than 65%; -1 is given when the coverage rate is 65% or more, but less than 70%; standard evaluation (0) is given when the transit station coverage rate is 70% or more, but less than 75%; an evaluation of +1 is given when the coverage rate is 75% or more, but less than 80%; the best evaluation of +2 is given when the transit station coverage is 80% or more.

④ Velocity of public transport

a. Interpretation:
Velocity of public transport refers to the ratio of commuting time by public transport to commuting time by auto during peak hours. It is an indicator evaluating the difference in commuting time by public transport and by auto between main home and work areas.

In order to improve the attractiveness of public transport services, especially to attract passengers of choice, public transport need to offer competitive travel times when compared to individual motorized transport. A rapid public transport service can effectively reduce people's dependence on private cars.

b. Evaluation scale: Scale 3

c. Type: Essential

d. Data source: Field study (questionnaire survey)

e. Methodology:
In this evaluation, the best evaluation (+2) is granted when the commuting time by public transport is not more than commuting time by auto; +1 is granted when the ratio of commuting time by public transport to commuting time by auto is above 1 but not more than 1.5; standard evaluation (0) is given when the ratio is above 1.5 but not more than 2; an evaluation of -1 is given when the ratio is above 2 but not more than 2.5; -2 is given when the commuting time by public transport is over 2.5 times more than the commuting time by auto.

⑤ Average wait-time in the highest peak hour

a. Interpretation:
Average wait-time in the highest peak hour is an important indicator reflecting the

overall service level of a city’s public transport system.

Passengers prefer wait-time in a range of 1 to 4 minutes, and a wait-time of 10 to 20 minutes is the upper limit (Meakin 2004). Long wait-times will ultimately push passengers to choose alternative modes of transport, such as private cars. Therefore, minimizing wait-time is fundamental to enhance the competitiveness of public transport services when compared to private car.

b. Evaluation scale: Scale 3

c. Type: Essential

d. Data source: Transport department

e. Methodology:
In this evaluation, +2 is granted when the average wait-time in the highest peak hour is less than 3 minutes; +1 is granted when the average wait-time is in a range of 3 to 5 minutes; standard evaluation (0) is given when the average wait-time is in the region of 6 to10 minutes; -1 is evaluated when the average wait-time is 11 to 20 minutes; the worst evaluation (-2) is evaluated when the average wait-time is longer than 20 minutes.

⑥ Emission level of buses

a. Interpretation:
Emission level of buses is an indicator evaluating the emission level of most buses in a city.

By applying stricter emission standards, per-unit emissions from motorized travel can be reduced. As attention focuses more and more on the human and environmental costs of both local pollutants and global climate change, the use of cleaner vehicles has become an inevitable choice. Since buses play an important role in the urban transport system, the choice of bus technology is important.

b. Evaluation scale: Scale 3

c. Type: Expanded

d. Applicable condition and scope:
This is an optimization indicator. Considering the actual social and economic foundation, it is suggested to be applied in big cities. At present, applying this indicator in middle- and small-sized cities is less feasible.

e. Data source: Transport department, development and reform commission, environmental protection department

f. Methodology:

In this evaluation, the National Discharge Standard of Vehicle Pollutant (Ⅰ-Ⅴ Stage) are taken as references. The best evaluation of +2 is granted when most vehicles meet the National Discharge Standard of Vehicle Pollutant (Ⅴ Stage); +1 is granted when most vehicles meet the National Discharge Standard of Vehicle Pollutant (Ⅳ Stage); an evaluation of 0 is assigned when most vehicles meet the National Discharge Standard of Vehicle Pollutant (Ⅲ Stage); -1 is evaluated when most vehicles meet the National Discharge Standard of Vehicle Pollutant (Ⅱ Stage); -2 is evaluated when most vehicles meet only the National Discharge Standard of Vehicle Pollutant (Ⅰ Stage).

⑦ Quality of public transport vehicles

a. Interpretation:

Quality of public transport vehicles is a significant determinant of the comfort of public transport service.

Passengers probably do not care about the emission level of vehicles, but they do care about the passenger service features that affect the journey comfort, convenience and safety. Unsatisfactory vehicle quality can reduce the attractiveness of public transport services, hence, in the long run, might support a modal shift towards comfortable private cars for those who can afford them.

b. Evaluation scale: Scale 3

c. Type: Expanded

d. Applicable condition and scope:

This is an optimization indicator. Considering the actual social and economic foundation, it is suggested to be applied in big cities. At present, applying this indicator in middle- and small-sized cities is less feasible.

e. Data source: Transport department, development and reform commission

f. Methodology:

The evaluation of quality of vehicles of public transport includes four criteria: i) air-conditions; ii) wide doors; iii) passenger travel information; iv) entertainment (e.g. TV, internet service). The best valuation of +2 is granted when most of the vehicles fulfill all criteria; an evaluation of +1 is granted when most of the vehicles fulfill 3 criteria; standard evaluation of 0 is assigned when most of the vehicles fulfill 2 criteria; -1 is evaluated when most of the vehicles fulfill 1 criterion; -2 is given when most of the vehicles do not fulfill any criterion.

⑧ Quality of public transport stations

a. Interpretation:
Quality of public transport stations is one of the crucial factors in ridership and customer satisfaction. The difference between a pleasant and safe waiting environment and a poorly maintained station can be the difference between customers choosing public transport over other alternative options.

An attractive station will likely be composed of a range of components, including: comfortable shelters and waiting areas; ticket machine; passenger travel information provision; sufficient lighting; barrier-free facilities; bicycle parking infrastructures; small scale shopping possibilities.

b. Evaluation scale: Scale 3

c. Type: Expanded

d. Applicable condition and scope:
This is an optimization indicator. Considering the actual social and economic foundation, it is suggested to be applied in big cities. At present, applying this indicator in middle- and small-sized cities is less feasible.

e. Data source: Transport department, development and reform commission

f. Methodology:
The evaluation of quality of public transport stations includes seven criteria: i) canopy; ii) ticket machine; iii) passenger travel information; iv) lighting; v) barrier-free access; vi) bicycle parking infrastructure; vii) small scale shopping possibility nearby. Evaluation objects in which most stations fulfill all criteria get the best evaluation of +2; no criterion fulfilled gets the worst result of -2; most stations fulfilling 1-2 criteria get an evaluation of -1; most stations fulfilling 3-4 criteria get the standard evaluation of 0; most stations fulfilling 5-6 criteria receive the evaluation of +1.

(3) Non-motorized transport

① Connectivity of footpaths

a. Interpretation:
Connectivity of footpaths refers to the coverage and accessibility of footpaths.

Non-motorized transport, including walking and cycling, is the essence of a low-carbon transport system in a city, since it offers mobility without producing any greenhouse gases and pollution. The existence of a full-coverage footpath / cycle track network influences people’s choice of travel mode and the liveliness of the area. The more options people have to travel by foot or by bicycle, the more they will make use of them. It is disturbing when some areas lack an appropriate footpath / cycle track network. This fundamentally limits the desire to travel by non-motorized transport.

b. Evaluation scale: Scale 2

c. Type: Essential

d. Data source: Transport department

e. Methodology:
The evaluation of connectivity of footpaths takes reference of the LCI®. The best evaluation of +2 is evaluated when there is a full-coverage footpath network separate from the main streets and with good connection to surrounding areas; +1 is evaluated when there is a full-coverage footpath network separate from the main streets, and the major facilities are accessible by the network; the standard evaluation of 0 is given when there is a full-coverage footpath network separate from the main streets; an evaluation of -1 is given when there is a full-coverage footpath network with footpath along the main streets; -2 is given when there is an incomplete footpath network.

② Quality of footpaths

a. Interpretation:
Quality of footpaths determines the pedestrian amenities.

If the footpath is of poor quality, even for short distances, motorized vehicles can be the mode of choice. Safe and comfortable conditions for walking can enhance pedestrians' experience and then promote more extensive use of the network. Generally, an attractive walking environment should have certain quality features, such as satisfactory path-width, the separation of footpath from motorized vehicles, lighting, street furniture, greening, etc.

b. Evaluation scale: Scale 3

c. Type: Essential

d. Data source: Transport department, urban construction department

e. Methodology:
In this evaluation, most footpaths are separated from motorways, with sufficient width, furniture, lighting, and greening, receive the best evaluation of +2; most footpaths are separated from motorways, with sufficient width, receive +1; footpaths with usable width, good furniture, lighting and greening, and along main roads with separation from motorways get the standard evaluation of 0; footpaths with usable width get -1;

very narrow and hardly usable footpaths are evaluated with -2 points.

③ Connectivity of cycle tracks

a. Interpretation:
Connectivity of footpaths refers to the coverage and accessibility of cycle tracks.

As described in the interpretation of the indicator "connectivity of footpaths", the connectivity of cycle tracks is also the essence of low-carbon transport system in a city.

b. Evaluation scale: Scale 2

c. Type: Essential

d. Data source: Transport department

e. Methodology:
The evaluation of connectivity of footpaths takes reference of the LCI®. The best evaluation of +2 is evaluated when there is a full-coverage cycle track network separate from the main streets and with good connection to surrounding areas; +1 is evaluated when there is a full-coverage cycle track network separate from the main streets, and the major facilities are accessible by the network; the standard evaluation of 0 is given when there is a full-coverage cycle track network separate from the main streets; an evaluation of -1 is given when there is a full-coverage cycle track network with footpath along the main streets; -2 is given when there is an incomplete cycle track network.

④ Quality of cycle tracks

a. Interpretation:
Quality of footpaths determines the cyclist amenities.

Cycling is a highly beneficial transport mode. In urban traffic, the use of bicycles should often be supported by providing quality basic facilities, such as satisfactory path-width, the separation of footpaths from motorized vehicles, lighting, street furniture, greening, etc. Bad or unattractive cycle tracks are only used in exceptions.

b. Evaluation scale: Scale 3

c. Type: Essential

d. Data source: Transport department, urban construction department

e. Methodology:

In this evaluation, most tracks are separated from motorways, with sufficient width, furniture, lighting, and greening, receive the best evaluation of +2; where most tracks are separated from motorways, with sufficient width, receive +1; tracks with usable width, good furniture, lighting and greening, and along main roads with separation from motorways get the standard evaluation of 0; tracks with usable width get -1; very narrow and hardly usable tracks are evaluated with -2 points.

⑤ Non-motorized vehicle parking

a. Interpretation:
Non-motorized vehicle parking is an indicator evaluating the existence and quality of non-motorized vehicle parking spaces.

Sufficient and well-equipped parking space is quite important in realizing the full usability of non-motorized vehicle, e.g. bicycle. Parking facilities at major destinations, such as workplaces, universities and schools, shopping areas, and hospitals, etc., help to make the use of non-motorized vehicles more convenient.

b. Evaluation scale: Scale 3

c. Type: Essential

d. Data source: Transport department, urban construction department

e. Methodology:
The evaluation of non-motorized vehicle parking includes four criteria: i) sufficient parking spaces at important public service facilities and public transport stops; ii) well-equipped bicycle racks and lighting; iii) good security; iv) clear signage. The best evaluation of +2 is granted when all criteria fulfilled by most of the parks; no criterion fulfilled get the worst result of -2; most stations fulfilling 1 criteria get an evaluation of -1; most stations fulfilling 2 criteria get the standard evaluation of 0; most stations fulfilling 3 criteria receive the evaluation of +1.

(4) Freight transport

① Main freight transport modes

a. Interpretation:
Main freight transport modes fundamentally influence carbon emissions from the freight transport sector in a city.

In most Chinese cities, freight transport relies on road infrastructure, with most high GHG emission and pollution motorized road transport forms, but less so on rail and waterways. According to a study in 2010, one ton-mile by truck emits about 1.9 pounds of CO_2, by rail transport generates 0.64 pounds of CO_2, and barge/river transport generates only 0.2 pounds (Herzog 2010). Since the rail and waterways are more environmentally- and climate-friendly modes, they should be fostered for freight transport wherever possible.

b. Evaluation scale: Scale 1

c. Type: Essential

d. Data source: Transport department

e. Methodology:
The best evaluation of +2 is granted if port-rail-road is the main freight transport mode; standard evaluation of 0 is given if rail-road or port-road is the main freight transport mode; the worst evaluation of -2 is given when road transportation is the only mode.

② Prioritization for low emission trucks

a. Interpretation:
Prioritization for low emission trucks is an indicator evaluating the incentives promoting the use of low emission trucks in urban freight transport.

Freight traffic with trucks plays an important role in urban freight transport over the past ten years in China. Trucks, as well as private cars, have become one large contributor of CO_2 emissions. Adopting low emission trucks can reduce the energy consumption and associated CO_2 emissions. However, cleaner technologies are generally more expensive than conventional technologies. In this case, it is unlikely that operators will introduce low emission trucks on their own initiative. Thereby, the establishment of a series of policies and incentives promoting the use of low emission trucks could provide better guidance to the development of low-carbon freight transport.

b. Evaluation scale: Scale 3

c. Type: Expanded

d. Applicable condition and scope:
This is an optimization indicator. Considering the actual social and economic foundation, it is suggested to be applied in big cities. At present, applying this indicator in middle- and small-sized cities is less feasible.

e. Data source: Transport department

f. Methodology:

In the evaluation of “prioritization for low emission trucks”, five criteria are involved: i) Subsidies and tax concessions to encourage the purchase and use of low emission vehicles; ii) permission to enter auto restricted zones; iii) no restriction for delivering time periods; iv) recharging devices in delivering zones; v) special delivering zones only for low emission trucks. Evaluation objects which fulfill all criteria get +2 points; 3 criteria fulfilled receive an evaluation of +1; 2 criterion fulfilled is evaluated at 0; 1 criterion fulfilled get -1; the worst evaluation of -2 is given when no criterion are fulfilled.

4.3.3 Indicators of energy

In LCISS, the energy sector contains 2 second-class indicators and 6 third-class indicators (Appendix 12).

(1) Energy supply side

① Main sources of energy supply

a. Interpretation:
The indicator of *Main sources of energy supply* refers to the components of a city’s energy structure.

As discussed, fossil fuels are the main sources of energy supply worldwide, and also one of the biggest contributors of CO_2 emissions, meanwhile, excessive consumption of fossil fuels leads to serious environmental pollution and energy crisis. With this background, integrating renewable energy, new energy and clean energy into the energy supply system can weaken the dependence on one certain energy source, so the energy supply can be safer and more climate-resilient.

b. Evaluation scale: Scale 1, 2 and 3

c. Type: Essential

d. Data source: Development and reform commission, urban construction department

e. Methodology:
An evaluation of -2 is given when there is only conventional energy supply, including power grid, gas network, and heating network; standard evaluation of 0 is given when there is one auxiliary energy source, such as waste heat, renewable energy, multi-generation, etc., in addition to the conventional energy supply system; the best evaluation (+2) is granted when there are more than one auxiliary energy sources.

② Renewable energy production

a. Interpretation:
Renewable energy production refers to the proportion of energy used in a city in the form of renewable energy, such as solar, wind and geothermal energy. The formula is as follows:

Renewable energy production = (renewable energy production/total energy consumption) *100%

Expand the use of renewable energy, a carbon neutral energy source, is an active way of coping with climate change, environment pollution, and energy crisis caused by excessive use of fossil fuels (Peng 2012).

b. Evaluation scale: Scale 2 and 3

c. Type: Essential

d. Data source: Development and reform commission, statistics department

e. Methodology:
The evaluation of renewable energy production refers to the report of "China Renewable Energy Outline 2012" (China National Renewable Energy Centre 2013). The best evaluation (+2) is granted when renewable energy production covers at least 20% of total energy consumption; an evaluation of +1 is granted when renewable energy production covers 15% or more but less than 20% of total energy consumption; standard evaluation (0) is assigned when renewable energy production covers 10% or more but less than 15% of total energy consumption; -1 is given when renewable energy production covers 5% or more but less than 10% of total energy consumption; an evaluation of -2 is given when renewable energy production covers less than 5% of total energy consumption.

③ Electricity production by co-generation

a. Interpretation:
Electricity production by co-generation refers to the proportion of electricity used in a city that is generated by co-generation. The formula is as follows:

Electricity production by co-generation = (electricity generated by co-generation system /total electricity consumption) *100%

Co-generation[29] is a technology generating electricity and heat simultaneously, which has higher efficiency than mono-generation. Moreover, co-generation is an important distributed generation technology that can reduce the impact of climate change on the energy supply system.

[29] For more information about co-generation, visit http://www.cogeneurope.eu/what-is-cogeneration_19.html

b. Evaluation scale: Scale 2 and 3

c. Type: Essential

d. Data source: Development and reform commission, statistics department

e. Methodology:

This evaluation refers to the “Evaluation System for Low Carbon Industrial Development Zone”. An evaluation of -2 is given when there is no electricity generated by co-generation; the standard evaluation of 0 is given when there is less than 5% of electricity generated by co-generation; the best evaluation (+2) is granted when there is at least 5% of electricity generated by co-generation.

(2) Energy demand side

① Green electricity contract

a. Interpretation:

Green electricity contract is an indicator evaluating the existence of a green electricity program.

Under green electricity programs, utilities purchase or generate renewable-sourced electricity, and supply it as a distinct product to users. The end users have the option to purchase and use part or all of their electricity from the green sources. Through promoting the purchasing and use of low-carbon energy, the CO_2 emissions associated with electricity/heat consumption can be reduced.

b. Evaluation scale: Scale 3

c. Type: Expanded

d. Applicable condition and scope:

“Green electricity contract” is an optimization indicator. Considering the actual social and economic foundation, applying this indicator in middle- and small-sized cities is less feasible at present, thus it is suggested to be applied in big cities.

e. Data source: Urban construction department, commission of economy and informatization, development and reform commission

f. Methodology:

In this evaluation, the best evaluation of +2 is granted when a green electricity program is implemented; if not, an evaluation of -2 is given.

② Incentive policy of renewable energy utilization

a. Interpretation:
Incentive policy of renewable energy utilization is an indicator evaluating the existence of policies encouraging the use of renewable energy. It mainly includes the following forms: fiscal subsidies, tax concessions, and low-interest loan, etc.

b. Evaluation scale: Scale 3

c. Type: Essential

d. Data source: Development and reform commission

e. Methodology:
Evaluation of +2 is granted when incentive policies of renewable energy have been issued and implemented; the standard evaluation of 0 is granted when incentive policies are under development; evaluation of -2 is given when there is no policy promoting renewable energy utilization.

③ Metered heating rate

a. Interpretation:
Metered heating rate refers to the percentage of buildings that have heating meters for individual units/tenants and are being billed by the meter. The formula is as follows:

Metered heating rate = (floor area of charge collection by heat metering/ total floor area) * 100%

Through the implementation of heat metering and consumption-based billing, end-use efficiency of heat can consequently be effectively enhanced, benefitting the climate and environment.

b. Evaluation scale: Scale 3

c. Type: Essential

d. Data source: Development and reform commission, statistics department,

e. Methodology:
According to the "Standards for Urban Heat Metering Reform Inspection" (Ministry of Housing and Urban-Rural Development of the People's Republic of China 2012), the best evaluation (+2) is granted when the metered heating rate of residential building is at least 25%, the rate of public building is at least 50%; an evaluation of +1 is given when the rate of residential building is 20% or more but less than 25%, the rate of public building is 40% or more but less than 50%; standard evaluation is given when the rate of residential building is 15% or more but less than 20%, the rate of public

building is 30% or more but less than 40%; -1 is evaluated when the rate of residential building is 10% or more but less than 15%, the rate of public building is 20% or more but less than 30%; the worst evaluation of -2 is given when the rate of residential building is below 15%, the rate of public building is below 20%.

4.3.4 Indicators of building

In LCISS, the building sector contains 2 second-class indicators and 3 third-class indicators (Appendix 12).

(1) New buildings

① Qualification ratio of building energy efficiency in new buildings

a. Interpretation:
Qualification ratio of building energy efficiency in new buildings refers to the percentage of new buildings attaining building energy codes relative to new buildings. The formula is:

Qualification ratio of building energy efficiency in new buildings = (area of new buildings attaining building energy codes / total area of new buildings)

For improving the building energy efficiency, a comprehensive building energy code system has been developed in China (Table 4.8). It contains design standards and acceptance codes, covering residential and public buildings, all major climate zones, and the main construction processes, which includes design, construction, acceptance, operation and retrofit (Bin and Jun 2012).

Table 4.8 Building energy codes system

Building Energy Codes		Contents
Design Standard	Design Standards for Energy Efficiency of Residential Buildings in Severe Cold and Cold Zones (1986, 1995[30] and 2010)	Building energy efficiency requirements for building envelope, thermal insulation, heating and ventilation.
	Design Standards for Energy Efficiency of Residential Buildings in the Hot Summer and Cold Winter Zone (2001 and 2010)	Building envelope and thermal insulation, and energy efficiency for heating, air conditioning and ventilation systems (HVAC).
	Design Standards for Energy Efficiency of Residential Buildings in the Hot Summer and Warm Winter	Thermal engineering for walls and roofs, shading, and energy efficiency for HVAC.

30 The 1986 and 1995 versions are entitled the "Energy Conservation Design Standards for Civil Buildings (Heating of Residential Buildings)".

	Zone (2003)	
	Design Standards for the Energy Efficiency of Public Buildings (2005)	Building energy efficiency indexes and requirements by climate zone, building envelope, thermal insulation, HVAC.
Acceptance Standard	Code for Acceptance of Energy Efficient Building Construction (2007)	Provisions for building energy efficiency construction works for walls, curtain walls, doors and windows, roofs, floors, HVAC, piping networks for space heating and air conditioning systems, power distribution and lighting, monitoring and control, and on-site inspections, among others.

Source: (Bin and Jun 2012)

b. Evaluation scale: Scale 2 and 3

c. Type: Essential

d. Data source: Urban construction department

e. Methodology:
According to the inspection results offered by the Ministry of Housing and Urban-Rural development, the compliance ratio with building energy codes at construction stage has achieved 95.4% in 2010 (Ministry of Housing and Urban-Rural Development of the People's Republic of China 2012). Taking this as reference, the standard evaluation of 0 is given when the qualification ratio is 95% or more but less than 100%; the best score of +2 is given when the ratio achieves 100%; an evaluation of -2 is given when the qualification ratio is below 95%.

② Proportion of green buildings in new buildings

a. Interpretation:
Proportion of green buildings in new buildings refers to the percentage of green buildings certified relative to new constructions or buildings. The formula is as follows:

Proportion of green buildings in new buildings = (certified green buildings area / total area of new buildings) *100%

According to the "Evaluation Standard for Green Building (GB-T50378 2014)", a green building is defined as a building which is designed to maximize the degree of resource conservation (incl. saving energy, land, water and materials), to protect the environment and to reduce pollution during its life cycle, in order to provide healthy, suitable and high performance living space for people (Ministry of Housing and Urban-Rural Development of the People's Republic of China 2015). The evaluation of green building involves seven indexes, i.e. land saving and outdoor environment, energy saving and energy utilization, water saving and water resource utilization, material saving and material resource utilization, indoor environment quality, construction management, and operating management. All of these indexes play a significant role in improving energy efficiency and lowering associated carbon emissions from the building sector in a city.

b. Evaluation scale: Scale 2 and 3

c. Type: Essential

d. Data source: Urban construction department

e. Methodology:

The evaluation of proportion of green buildings in new buildings refers to two Chinese government documents. Firstly, according to the “Green Building Action Plan” till the end of 2015, 20% of new buildings in cities and towns should reach green building standards (National Development and Reform Commission of the People's Republic China and Ministry of Housing and Urban-Rural Development of the People's Republic of China 2013). The other reference is the “National New Urbanization Plan (2014-2020)”, in which the proportion of green buildings accounted for in the total new buildings should reach 50% by 2020 (State Council of China 2014).

Based on above, the best evaluation of +2 is granted when green buildings account for at least 50% of new buildings; standard evaluation of 0 is granted when the proportion of green buildings in new buildings is 20% or more but less than 35%; the worst evaluation of -2 is given when green buildings account for below 5% of new buildings; evaluation of +1 is given to performances between 0 and +2; and -1 is given to performances between 0 and -2.

(2) Existing buildings

① Qualification ratio of building energy efficiency in existing buildings

a. Interpretation:

Qualification ratio of building energy efficiency in existing buildings refers to the percentage of existing buildings attaining building energy codes relative to total existing buildings. The calculation formula is:

Qualification ratio of building energy efficiency in existing buildings = (area of existing buildings attaining building energy codes / total area of existing buildings)

As aforementioned, China has more than 50 billion square meters of existing building stocks, in which over 90% are high energy consuming (Qianzhan Business Information

Co. Ltd. Industry Research College 2014). Thereby, retrofitting existing buildings has considerable potential to lower the level of energy consumption and carbon emission. Energy efficiency retrofitting of existing buildings is to upgrade, renovate, or modify the building envelop, HAVC systems, illuminating apparatuses and other facilities which do not meet the mandatory building energy efficiency standards(Bin and Jun 2012).

b. Evaluation scale: Scale 2 and 3

c. Type: Expanded

d. Applicable condition and scope:
This indicator is not suggested to be applied when there is no existing building in the evaluation object, e.g. new city projects.

e. Data source: Urban construction department

f. Methodology:
According to the "Special Plan for Building Energy Efficiency in the 12^{th} Five-Year Plan", by 2010, the average qualification ratio of building energy efficiency in existing buildings is 23.1%. In some cities, such as Beijing, Tianjin, Shanghai, etc., this ratio is above 30%. Taking this as reference, the standard evaluation (0) is given when the qualification ratio is 20% or more but less than 30%; +1 is evaluated when the qualification ratio reaches 30% or more but less than 40%; the best evaluation (+2) is granted when the qualification ratio is over 40%; an evaluation of -1 is given when the qualification ratio is 10% or more but less than 20%; -2 is given when the ratio is below 10%.

4.3.5 Indicators of water

In LCISS, the water sector contains 3 second-class indicators and 8 third-class indicators (Appendix 12).

(1) Water supply

① Water supply from non-traditional sources

a. Interpretation:
Water supply from non-traditional sources refers to the percentage of water supply from non-traditional sources, such as recycled water, rain water, desalinated seawater, etc. The formula is as follows:

Water supply from non-traditional sources = (water supply from non-traditional sources / total water supply) * 100%

Encouraging the utilization of water from non-traditional sources will have the overall effect of alleviating the water shortage of Chinese cities and realizing highly efficient use of water resources.

b. Evaluation scale: Scale 2 and 3

c. Type: Essential

d. Data source: Water department

e. Methodology:
This evaluation takes the Evaluation Standard for Green Ecological Demonstration Area in Beijing as reference. Evaluation objects which have at least 20% water supply from non-traditional sources receive the best evaluation of +2; objects have 15% or more, but less than 20% non-traditional sourced water supply receive +1; standard evaluation is given when objects have 10% or more, but less than 15% non-traditional sourced water supply; objects have 5% or more, but less than 10% water supply from non-traditional sources get -1; and which have less than 5% get an evaluation of -2.

② Water tariff

a. Interpretation:
Water tariff is an indicator evaluating a city's water pricing method and the balance of payment.

Water tariff is an important economic instrument for controlling water demands and improving water use efficiency, thereby, it can increase resiliency and security of existing water supplies, and decrease the energy consumption of water extraction, transportation, treatment, heating, etc.

Increasing block water tariff (IBT) is known as a widely used method of water metering and pricing. The pricing system starts with a low water tariff within a defined block that increases when additional water is consumed, which is an effective method to adjust the relationship of water demand and supply using price lever. In China, the establishment of IBT system is regarded as one of the most important goals of water conservancy reform (National Development and Reform Commission of the People's Republic of China and Ministry of Housing and Urban-Rural Development of the People's Republic of China 2014).

b. Evaluation scale: Scale 3

c. Type: Essential

d. Data source: Water department, development and reform commission

e. Methodology:

The water price should be higher than the cost with little profit breakeven. In this evaluation, the best evaluation of +2 is granted when the IBT system is established, water price is higher than the cost, and charge rate achieves low profit breakeven; an evaluation of +1 is granted when the IBT system is established, water price is higher than the cost, but the charge rate cannot balance the payment; the standard evaluation is given when the IBT system is established, but the water price is lower than the cost; -1 is given when water price is higher than the cost, but there is no IBT system; -2 is given when there is no IBT system, and water price is lower than the cost.

③ Leakage rate

a. Interpretation:

Leakage rate refers to the ratio of unaccounted-for water to total water supply. It is an important measure of the efficiency of water supply system.

Leakage rate = [(annual water supply – metered annual water supply) / annual water supply] * 100%

b. Evaluation scale: Scale 3

c. Type: Essential

d. Data source: Water department

e. Methodology:

In compliance with the Standard for Leakage Control and Assessment of Urban Water Supply Distribution System (CJJ92-2002), the leakage rate should be less than 12% of flow (Ministry of Construction of the People's Republic of China 2002)[31]. Taking the Evaluation Standard for Water-Saving City as reference (Ministry of Housing and Urban-Rural Development of the People's Republic of China and National Development and Reform Commission of the People's Republic China 2012), the best evaluation (+2) is granted when the leakage rate is not more than 10%; the standard evaluation of 0 is given when the leakage rate is 12%; the worst evaluation of -2 is given when the leakage rate is 14% or more; -1 is evaluated to performances between 0 and -2; and +1 is evaluated to performances between 0 and +2.

④ Coverage of water-saving appliances

a. Interpretation:

The indicator of *coverage of water-saving appliances* refers to the ratio of water-saving appliance to the total number of water appliance. The formula is as follows:

[31] Since 2008, the Ministry of Construction of the People’s Republic of China was renamed “Ministry of Housing and Urban-Rural Development of the People’s Republic of China”.

Coverage of water-saving appliances = (number of water-saving appliance / total number of water appliance) * 100%

The wide use of water-saving appliances can effectively improve the water use efficiency, thus reducing water demand and associated energy consumption and carbon emissions. According to the national standard of “Domestic Water Saving Devices (CJ164-2002)” (Ministry of Construction of the People's Republic of China 2002), water-efficient appliances can be defined as an appliance, installation of which can reduce the amount of water consumption, meanwhile, meeting various needs such as drinking, kitchen, toilet, bath and laundry.

b. Evaluation scale: Scale 3

c. Type: Expanded

d. Applicable condition and scope:

At present, the utilization of water-saving appliances in small-sized cities is obviously less than in big and middle-sized cities in China. According to the Evaluation Index on Green and Construction for Key Small Cities & Towns (Trial), the best evaluation is granted when the coverage of water-saving appliances is not less than 90%. However, in accordance with the Standard for Water-Saving City (Ministry of Housing and Urban-Rural Development of the People's Republic of China and National Development and Reform Commission of the People's Republic China 2012), the best evaluation is granted only when the coverage rate achieves 100%. Therefore, considering the actual social and economic foundation, this indicator is suggested to be applied in big and middle-sized cities.

e. Data source: Field sampling

f. Methodology:

Taking the Evaluation Standard for Water-Saving City as reference (Ministry of Housing and Urban-Rural Development of the People's Republic of China and National Development and Reform Commission of the People's Republic China 2012), the best evaluation (+2) is granted when the coverage of water-saving appliances is 100%, +1 is granted when the coverage rate is 92% or more but less than 100%; 0 is evaluated when the coverage rate is 84% or more but less than 92%; an evaluation of -1 is given when the coverage rate is 76% or more but less than 84%; the worst evaluation is given when the coverage rate is below 76%.

(2) Wastewater treatment

① Treatment rate of wastewater

a. Interpretation:

Treatment rate of wastewater refers to the percentage of wastewater treated up to Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant (GB18918-2002) (State Environmental Protection Administration of the People's Republic of China and State Administration for Quality Supervision and Inspection and Quarantine of the People's Republic of China 2002). The formula is as follows:

Treatment rate of wastewater = (wastewater meeting discharge standard / total wastewater discharge) * 100%

Efficient wastewater treatment can avoid the massive GHGs emissions (incl. nitrogen dioxide, methane, and carbon dioxide) caused by "natural" treatment processes without proper control.

b. Evaluation scale: Scale 2 and 3

c. Type: Essential

d. Data source: Water department, statistics department

e. Methodology:
Previous statistics showed that the average treatment rate of wastewater of Chinese cities was 87.3% (Ministry of Housing and Urban-Rural Development of the People's Republic of China 2013). In this evaluation, the standard evaluation of 0 is given when the treatment rate is similar to the average level; +1 is evaluated when the treatment rate is not more than 10% above the average level; +2 is evaluated when the treatment rate is more than 10% above the average level; -1 is evaluated when the treatment rate is not more than 10% below the average level; -2 is evaluated when the treatment rate is over 10% below the average level.

(3) Stormwater management

① Stormwater and wastewater diversion

a. Interpretation:
Stormwater and wastewater diversion is an indicator evaluating whether stormwater and wastewater diversion is implemented in new urban areas, and is planned to upgrade in built-up urban areas.

Stormwater and wastewater diversion is a sewage system that stormwater and sewage are diverted into separate channels: stormwater is directly sent into rivers and lakes, while sewage is sent to waste treatment plants, where contaminants are filtered out. This can effectively lower the cost of wastewater treatment and reduce the associated energy consumption and emissions. Moreover, in cities with combined sewer systems, the impacts of climate change will lead to more overflow events and untreated sewage into surrounding water bodies (Kenward, Yawitz et al. 2013).

b. Evaluation scale: Scale 2 and 3

c. Type: Essential

d. Data source: Water department

e. Methodology:
In this evaluation, +2 is granted when a stormwater and wastewater diversion system is implemented in new urban areas, and is planned to be upgraded in built-up urban areas; evaluation objects that do not meet this standard receive an evaluation of -2.

② Drainage system

a. Interpretation:
Drainage system is an indicator evaluating whether drainage systems meet the Code for Design of Outdoor Wastewater Engineering (GB50014-2006) (Ministry of Housing and Urban-Rural Development of the People's Republic of China and State Administration for Quality Supervision and Inspection and Quarantine of the People's Republic of China 2006).

Climate change could make urban drainage systems face more serious challenges, since it will be highly affected by increasingly frequent and intense precipitation. Therefore, in cities affected by increasing heavy storms, the performance of drainage systems and flood prevention systems determines a city's climate resilience.

b. Evaluation scale: Scale 2 and 3

c. Type: Essential

d. Data source: Water department, urban construction department

e. Methodology:
In this evaluation, the standard evaluation of 0 is given when the drainage system meets the national standards; the best evaluation (+2) is granted when the drainage system is above the national standard; -2 is evaluated when the drainage system does not meet the national standard.

③ Flood prevention

a. Interpretation:
Flood prevention is an indicator evaluating whether a city's flood control facilities meet the Code for Design of Urban Flood Control Project (GB/T50805-2012) (Ministry of

Water Resources of the People's Republic of China 1994, Ministry of Housing and Urban-Rural Development of the People's Republic of China and State Administration for Quality Supervision and Inspection and Quarantine of the People's Republic of China 2012), especially in key urban areas, hub areas, underground public spaces, equipped with sound drainage facilities and effective maintenance.

b. Evaluation scale: Scale 2 and 3

c. Type: Essential

d. Data source: Water department, urban construction department

e. Methodology:
In this evaluation, the Code for Design of Urban Flood Control Project (GB/T50805-2012) is taken as reference. According to a study in 2008, only 37% of Chinese cities could meet this national flood control standard (Fang, Zhong et al. 2008). The standard evaluation of 0 is given when the flood control facility meets the national standard; the worst evaluation of -2 is given when the flood control facility does not meet the national standard; the best evaluation of +2 is granted when the flood control facility is above the national standard.

4.3.6 Indicators of municipal solid waste

In LCISS, the sector of municipal solid waste (MSW) contains 2 second-class indicators and 5 third-class indicators (Appendix 12).

(1) MSW collection & transfer

① Waste collection rate

a. Interpretation:
Waste collection rate refers to the municipal solid wastes collected over that produced. The formula is as follows:

Waste collection rate = (quantity of collected and transported MSW/ total quantity of MSW) *100%

Badly collected and transferred waste is a source of contamination for water and soil, contributes to air pollution, emits GHGs, and even increases the risk of flood. Uncollected waste also poses a threat to public health by attracting vectors of disease such as mosquitoes, flies, and rodents.

b. Evaluation scale: Scale 2 and 3

c. Type: Essential

d. Data source: Sanitation department, environmental protection department, statistics department

e. Methodology:
The evaluation of waste collection rate is on the basis of experts' consultation. The best evaluation (+2) is granted when the collection rate is 100%; +1 is evaluated when the collection rate is at least 90% but less than 100%; 0 is evaluated when the collection rate is at least 80% but less than 90%; an evaluation of -1 is given when the collection rate is at least 70% but less than 80%; -2 is given when the collection rate is below 70%.

② Proportion of communities with separate waste collection facilities

a. Interpretation:
Proportion of communities with separate waste collection facilities refers to the proportion of communities that implemented a separate waste collection to all communities. The formula is as follows:

Proportion of communities with separate waste collection facilities = (number of communities with separate waste collection / total number of communities) * 100%

The implementation of separate waste collection facilities can significantly improve the quality of materials for recycling and optimize incineration, in turn delivering benefits in CO_2 emission savings. Additionally, separate waste collection can also greatly reduce the energy consumption during the waste sorting process.

The Chinese government has implemented waste segregation for 20 years; however, there has been only limited success. Since the relative statistical data is not available, the LCISS uses the indicator "proportion of communities with separate waste collection" instead, in order to promote waste segregation.

b. Evaluation scale: Scale 3

c. Type: Essential

d. Data source: Sanitation department, environmental protection department

e. Methodology:
The best evaluation of +2 is granted when the proportion of communities with separate waste collection facilities is not less than 45%; +1 is granted when the proportion is 30% or more but less than 45%; the standard evaluation (0) is given when the proportion is 15% or more but less than 30%; -1 is evaluated when there are communities with separate waste collections, but the proportion is below 15%; -2 is evaluated when there

is no community with separate waste collection facilities.

③ Emission level of waste transport vehicles

a. Interpretation:
Emission level of waste transport vehicles is an indicator evaluating the emission level of most waste transport vehicles in a city.

By applying stricter emission standards, per-unit emissions from motorized travel can be reduced. As attention focuses more and more on the human and environmental costs of both local pollutants and global climate change, the use of cleaner vehicles has become an inevitable choice.

b. Evaluation scale: Scale 3

c. Type: Expanded

d. Applicable condition and scope:

This is an optimization indicator. Considering the actual social and economic foundation, it is suggested to be applied in big cities. At present, applying this indicator in middle- and small-sized cities is less feasible.

e. Data source: Sanitation department, environmental protection department

f. Methodology:
In this evaluation, the National Discharge Standard of Vehicle Pollutant (Ⅰ-Ⅴ Stage) are taken as references. The best evaluation of +2 is granted when most vehicles meet the National Discharge Standard of Vehicle Pollutant (Ⅴ Stage); +1 is granted when most vehicles meet the National Discharge Standard of Vehicle Pollutant (Ⅳ Stage); an evaluation of 0 is assigned when most vehicles meet the National Discharge Standard of Vehicle Pollutant (Ⅲ Stage); -1 is evaluated when most vehicles meet the National Discharge Standard of Vehicle Pollutant (Ⅱ Stage); -2 is evaluated when most vehicles meet only the National Discharge Standard of Vehicle Pollutant (Ⅰ Stage).

(2) MSW Disposal

① Landfilling rate

a. Interpretation:
Landfilling rate refers to the percentage of waste treated by landfilling. Its calculation formula is as follows:

Landfilling rate = (quantity of harmlessly treated MSW / quantity of collected and transported MSW) * 100%

Landfilling is the most widely-used method of waste disposal, which is a significant contributor of GHG emissions and occupies valuable land resources. Most Chinese cities are currently facing the predicament of being surrounded by waste. Thus, reducing the percentage of waste treated by landfilling is important to a city's low-carbon and sustainable development. Furthermore, since the statistical data of waste recycling rate is not available, the indicator of landfilling rate can indirectly reflect the level of waste recycling in a city.

b. Evaluation scale: Scale 2 and 3

c. Type: Essential

d. Data source: Sanitary department, statistics department

e. Methodology:
Statistics show that the waste landfilling rate was 74.87% (incl. sanitary landfilling 68.28% and simple landfilling 6.59%) in Chinese cities in 2012 (Ministry of Housing and Urban-Rural Development of the People's Republic of China 2013). According to this, the standard evaluation (0) is given when percentage of landfilling is similar to the average level; +1 is granted when the percentage of landfilling is below the average level but not more than 10%; +2 is granted when the percentage of landfilling is more than 10% below the average level; -1 is given when the percentage of landfilling is above the average level but not over 10%; -2 is given when the percentage of landfilling is more than 10% above the average level.

② Harmless treatment rate

a. Interpretation:
The term "harmless treatment" in China means the disposal of waste by recycling, composting, incineration and sanitary landfilling. Harmless treatment rate refers to the percentage of waste that received harmless treatment. Its calculation formula is:

Harmless treatment rate = (quantity of harmlessly treated MSW/quantity of collected and transported MSW) *100%

The improvement of harmless waste treatment is of significance to the construction of a safe and livable living environment and the reduction of potential risk of climate change.

b. Evaluation scale: Scale 2 and 3

c. Type: Essential

d. Data source: Sanitary department, environmental protection department, statistics department

e. Methodology:
Statistics show that the harmlessly treated waste accounted for 93% of all collected and transported waste in Chinese cities in 2012 (Ministry of Housing and Urban-Rural Development of the People's Republic of China 2013). According to this, the standard evaluation of 0 is given when the harmless treatment rate is similar to the average level; +1 is granted when the rate is above the average level but not more than 5%; +2 is granted when the rate is more than 5% above the average level; -1 is given when the harmless treatment rate is below the average level but not over 5%; -2 is given when the rate is more than 5% below the average level.

4.4 Summary

This chapter detailed the evaluation framework of Low-Carbon Indicator System – Sino (LCISS) and its development.

Firstly, based on the introduction of component and evaluation method of LCISS, a coupled evaluation model with urban planning and key urban sectors was established, and LCISS's framework was proposed, including three scales, i.e. macro, middle and micro scales, and six evaluation sectors, i.e. urban design, transport, energy, building, water, municipal solid waste. Furthermore, the function and products of LCISS were defined.

Secondly, the construction process of LCISS was studied. LCISS is organized as a three-level hierarchic structure that contains 54 indicators. All of the evaluation indicators are selected using the Theoretical Analysis and Delphi methods. Additionally, the types and values of indicator and method of weighting assignment were discussed.

Finally, all of the evaluation indicators were described in detail, including their interpretation, evaluation scale, type, data source, methodology, etc.

After LCISS was developed, it will be tested in practice in Chapter 5 through a case study of Sino-Singapore Tianjin Eco-City.

Chapter 5 A Case Study of Sino-Singapore Tianjin Eco-City

This chapter is dedicated to illustrating how the Low-Carbon Indicator System – Sino (LCISS) could be applied for evaluation of city development in the Chinese background. Sino-Singapore Tianjin Eco-City is selected as the case study for this work, since it is one of the most representative pilot projects in China, and it has good data availability and integrity.

5.1 Overview of Sino-Singapore Tianjin Eco-City

Sino-Singapore Tianjin Eco-City (SSTEC) is located in the northern part of the Tianjin Binhai New Area (TBNA) – one of the fastest growing and most strategically important areas in China. The project is adjacent to Tianjin Economic and Technological Development Area, Tianjin Port, Binhai Leisure and Tourism Area. It is 15km from the core area of TBNA, 45km from the Tianjin city center, and 150km from Beijing (Figure 5.1). SSTEC has a total land area of 34.2km^2 that is envisaged to house 350000 permanent residents by 2020.

Figure 5.1 Location of SSTEC
Source: (Singapore Goverment 2012)

Natural conditions in Eco-city are relatively poor with complex geological structure, weak soil quality, and high climate vulnerability. The ground bearing capacity is non-uniform in SSTEC, and there is significant land subsidence, especially in the northern part of the Eco-city. Unlike common practices of urban sprawl that usually encroach on arable land, the land for SSTEC mainly contains one-third non-arable land, one-third deserted salt pans, and one-third polluted water bodies. Given its coastal location, it is projected that SSTEC will be exposed to rising sea levels, and more frequent and intensive floods and storm surges.

SSTEC has convenient traffic conditions, since it is at the intersection of the Beijing-Tianjin urban development axis, and the Bohai rim coastal industrial zone. According to the Tianjin City Master Plan (2005-2020) and the Integrated Transport Planning of Binhai New Area (2006-2020), around the Eco-city, an excellent transportation network is planned, including Tianjin–Qinhuangdao High-Speed Railway, Beijing-Tianjin-Tangshan Intercity Railway, Light Railway, and a series of expressways and urban expressways.

As articulated in the master plan, the development timeframe of SSTEC is from 2008 to 2020 in three phases. This schedule provides the Eco-city flexibilities to optimize its planning during development while lowering the risks of new town development. Phase I has been implemented during 2008 to 2010, which covers a start-up area of 4.1 km^2 and involves a projected population of 85,000. Phase II is being implemented over 2011 to 2015. By the end t, fundamental spatial structure of the project will be completed, including major infrastructure and facilities, and the transport network linking it to the surrounding regions (Baeumler, Chen et al. 2009). Phase III (2016-2020) will be implemented over 5 years. By 2020, SSTEC will be fully developed.

5.2 Background and establishment of Sino-Singapore Tianjin Eco-City

China has been experiencing an unprecedented process of urbanization in the past decades. By the end of 2014, 54.77% of the total population lived in urban areas (Xinhua Net 2015), a rate that was 26.41% in 1990 and 36.22% in 2000 (Yu 2014). Meanwhile, China is also an illustrative example of how rapid urbanization can lead to negative impact on cities. The fast growth of urban population presents a series of challenges for Chinese cities, such as rapid urban expansion, growing resource and environmental pressures, increased energy consumption and GHGs emission, etc. Recognizing these issues, China is at a crucial stage in shifting its economic development-centered model towards a more sustainable one.

Under this background, SSTEC stands for one of China’s most important explorations, which aims to practice a more ecologically sustainable pattern of urban development. It is a significant collaborative project between China and Singapore in addressing climate changes, developing low-carbon economy, enhancing environmental protection, conserving resources and energy, and establishing harmonious society (Research Group of Key Performance Indicators for Sino-Singapore Tianjin Eco-City 2010). The project was mooted by the former Chinese Premier Wen Jiabao and Singapore Senior Minister Goh Chok Tong in April 2007, and a Framework Agreement to collaborate on

SSTEC was signed by China and Singapore in November 2007. In 2008, the master plan of the eco-city was completed and the construction was commenced.

5.3 Vision and characteristics of Sino-Singapore Tianjin Eco-City

The vision of SSTEC is to be a new city that is economically vibrant, environmentally friendly, resource-efficient and socially harmonious. It will provide a practicable (adoption of affordable and commercially viable technologies), replicable (its principles and models applicable to other cities in China and the rest of the world) and scalable (can be adapted for developments of different scales) reference of eco and low carbon city for other cities in China (Government of Singapore 2014). The Eco-city's target of carbon emission reduction is to produce only 150 tons of GHG emissions per million US$ GDP, which is the national average level in 2004 in China (Chen and Lu 2010).

To achieve the vision, an integrated approach involving urban planning, energy, transport, building, water, and waste has been adopted in SSTEC (Research Group of Key Performance Indicators for Sino-Singapore Tianjin Eco-City 2010).

- The main strategies of urban planning and spatial development in the Eco-city include: i) except in green open spaces and on water surfaces, a high density of 14000 people/m^2 is expected on the remaining 25km^2 land for construction; ii) per capita urban development land of 72.57m^2 is less than the 106m^2 in Tianjin and the national standard 85.1 ~ 105.0m^2; iii) mixed land use that all daily needs can be met within a walking distance of 500m; iv) "eco-cells", the 400 by 400m city blocks compose the spatial structure of the Eco-city.

- SSTEC is planned to be a city with strong green trip network, in which 90% of trips are required to be in the form of public and non-motorized transport. This strategy will be realized on the basis of the following main pillars: i) transit oriented development (TOD) that more than 90% of the residents and places of employment are concentrated within 500m of public transport hubs (Figure 5.2); ii) establish a high quality comprehensive public transport system, and apply green technology to public transport; iii) provide a well-designed non-motorized transport system characterized by high network density, separating motor and non-motor, and linking communities with main public facilities and public transport (tram/bus) stops.

- SSTEC promotes the utilization of renewable energy. It is expected that the annual energy demand in SSTEC will reach 486,900 tons of Standard Coal Equivalent (SCE) by 2020 (Baeumler, Chen et al. 2009). As planned, 80% of its total energy supply will be from conventional energy sources and 20% from renewable energy sources, such as solar, wind, and geothermal energy.

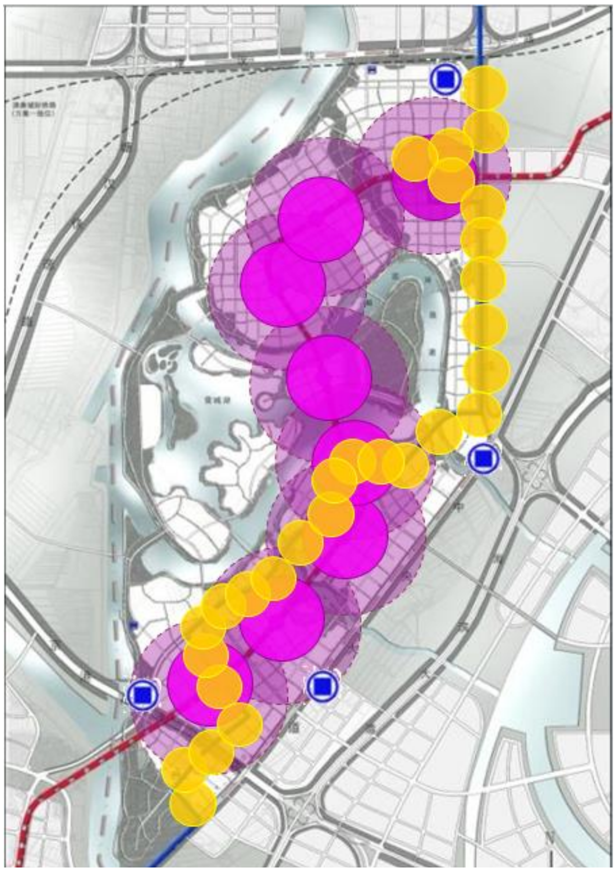

Figure 5.2 TOD in SSTEC
Source: (Lin 2008)

· All buildings in SSTEC are required to meet the "Green building design standard for Sino-Singapore Tianjin Eco-city (DB29-195-2010)" (Sino-Singapore Tianjin Eco-City Administrative Committee 2010), a benchmark even higher than the national green building standard.

· Because the Eco-city is located in a water-scarce region, it aims to meet at least 50% of its water supply from non-traditional sources, such as recycled water, harvested stormwater, desalinated seawater, etc. By 2020, the water demand in SSTEC is estimated to reach 153400m^3/day, including conventional water 74400m^3/day and non-traditionally sourced water 79000m^3/day.

· "Waste into resource" is the main concept of waste management in the Eco-city. According to SSTEC's master plan, daily per capita domestic waste production is projected to be limited to 0.8kg which is lower than the national standard "Code for Planning of Urban Environmental Sanitation Facilities (GB50337-2003)" (Ministry of Construction of the People's Republic of China 2003), and at least 60% of total waste in the Eco-city is required to be recycled.

In order to guide the development of SSTEC, an indicator system with 22 quantitative and 4 qualitative key performance indicators (KPIs) has been developed under four categories: "ecological and healthy environment", "social harmony and progress", "dynamic and efficient economy", and "integrated regional coordination" (Appendix 6).

5.4 LCISS evaluation of Sino-Singapore Tianjin Eco-City

In this section, the LCISS is applied to evaluate the level of low-carbon development of SSTEC. The source of data and information in this evaluation includes: i) publicly available statistical data; ii) government documents; iii) field study results and data obtained from interview with experts from Sino-Singapore Tianjin Eco-City Administrative Committee.

As mentioned in Chapter 4, the Low-Carbon Indicator System – Sino is an evaluation system consisted of 6 first-class indicators, 17 second-class indicators, and 54 third-class indicators. The third-class indicators include 41 essential indicators and 13 expanded indicators. According to SSTEC's practical situation, except the expanded indicator of "qualification ratio of building energy efficiency in existing buildings", all other indicators are applicable to the Eco-city.

In Table 5.1, Table 5.2 and Table 5.3, the weight of each indicator is assigned in compliance with the method discussed in 4.2.5 (Appendix 13), and the value of each indicator is given based on the performance of SSTEC.

5.4.1 LCISS evaluation of Sino-Singapore Tianjin Eco-City in Scale 1

(1) Urban Design

① "Original land use type"
The planned area for the Eco-city site is 34.2km^2, including 0.297km^2 village construction lands, 10.197km^2 salt pans, 4.789km^2 reservoirs, 0.244km^2 traffic lands, 0.599km^2 arable lands, 4.165 km^2 aquaculture water surface, 2.076km^2 river areas, and 11.833km^2 unused lands. Among them, the unused land took up the highest proportion of 34.6% of the total area. Thus, SSTEC's evaluation of the indicator "original land use type" is 0.

② "Disaster risk"
The land suitability of SSTEC was assessed by using the combined method of Analytic Hierarchy Process (AHP) and Global Information System (GIS). Based on that, four types of spatial management area were identified: prohibited-construction area, limited-construction area, built-up area, and buildable area. In the prohibited-construction areas, construction is banned entirely because of the high risk of natural disasters. In other words, there is no construction in high-risk areas in the Eco-city. Its evaluation of the indicator "disaster risk" is +2.

③ "Mixture of functions"
According to the plan, SSTEC's land use involves 8 categories and 19 classes of land use types of the "Code for classification of urban land use and planning standards of development land (GB50137-2011)". The 19 classes contain: first class of residential land, second class of residential land, administrative land, cultural facility land, educational and scientific land, sports facility land, healthcare facility land, cultural relics land, commercial facility land, first class of industrial land, first class of logistics and warehouse land, urban road construction land, transport station construction land, supplying facility land, environmental facility land, safety facility land, other public facility land, park green space, and green buffer. According to the calculation based on the formula of Simpson's diversity index, the land-use diversity index of SSTEC is 0.997. Its evaluation of the indicator "mixture of functions" is +2.

④ “Regional traffic connection”

According to SSTEC’s plan, the road network covers the entire area (Figure 5.3). Moreover, a multi-modal integrated public transport system is planned for the Eco-city (Figure 5.4), including rail transit (LRT), bus, tramcar, and taxi. Thus, the Eco-city’s evaluation of the indicator “regional traffic connection” is +2.

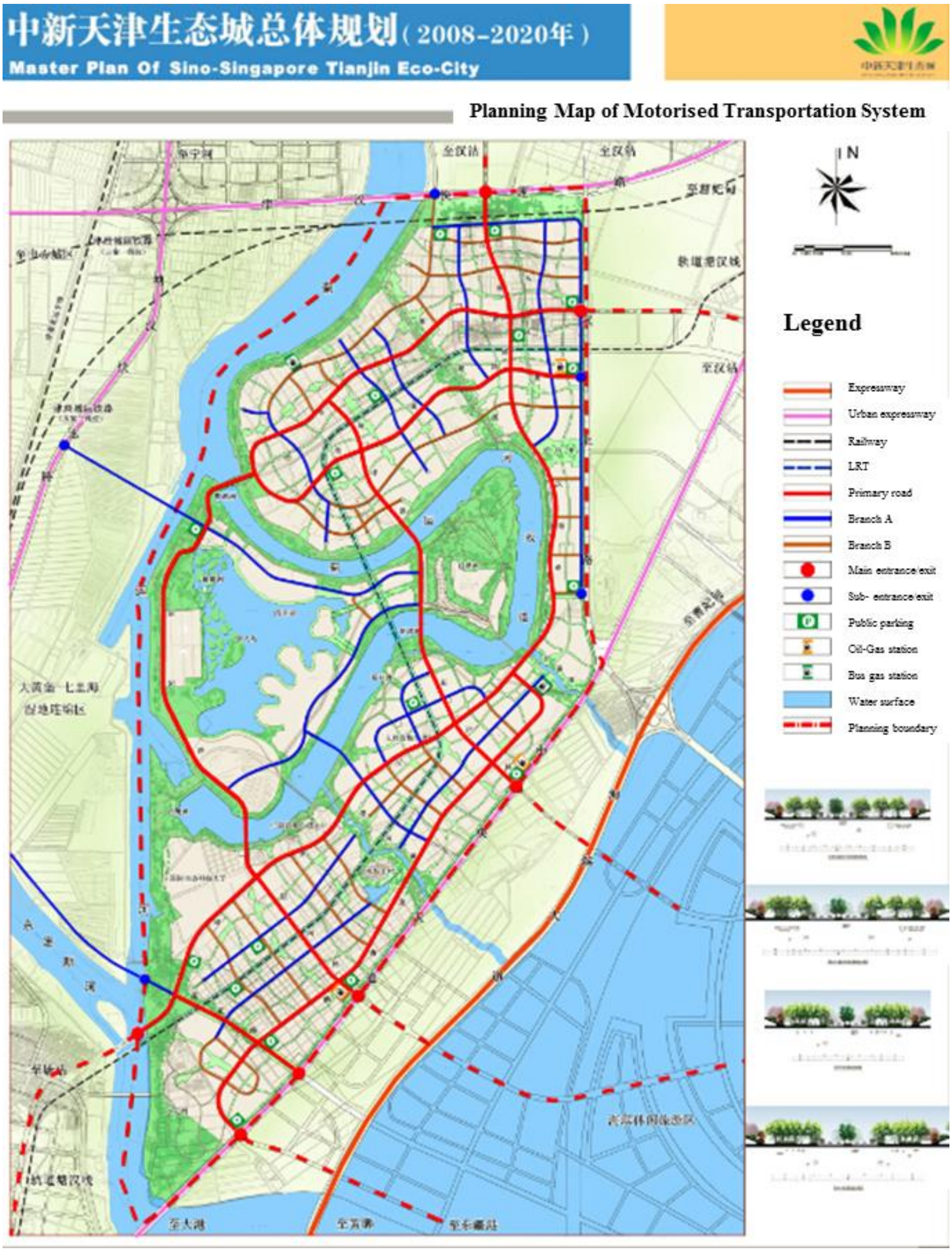

Figure 5.3 Planning map of motorized transportation system in SSTEC

Source: Sino-Singapore Tianjin Eco-City Administrative Committee

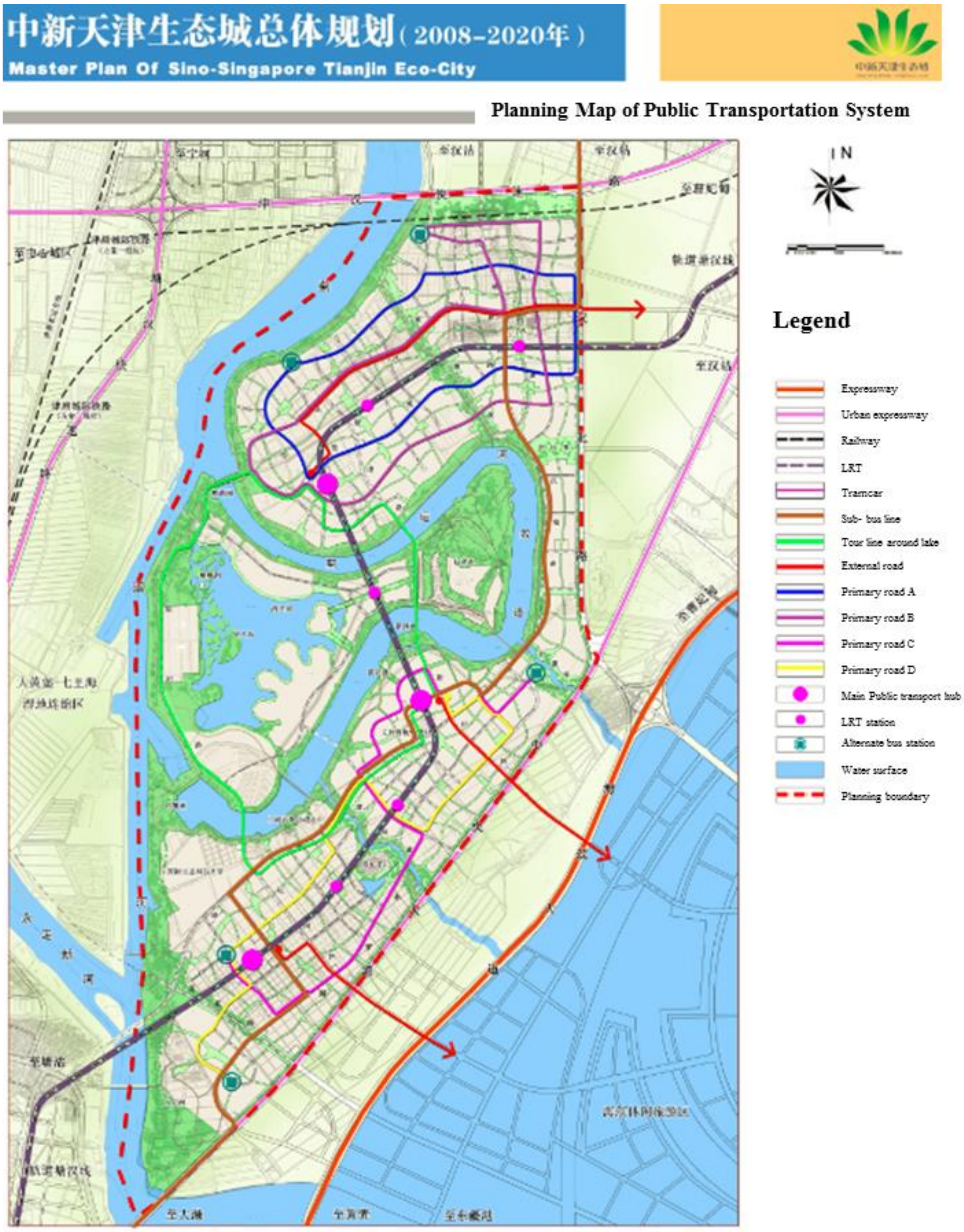

Figure 5.4 Planning map of public transportation system in SSTEC
Source: Sino-Singapore Tianjin Eco-City Administrative Committee

(2) Transport

① "Position in highway network"
Expressways around SSTEC include Tangjin Expressway, Tanghan Expressway, Second Jingjintang Expressway, and Binhai Boulevard. The nearest highway – Binhai Boulevard is less than 1km away from the east boundary of the Eco-city. In addition,

there are also three urban expressways around the Eco-city: Central Avenue (south-east boundary of SSTEC), Jinhan Urban Expressway (north boundary of SSTEC), and Tanghan Urban Expressway. In this context, the evaluation of "position in highway network" receives +2.

② "Main form of Mass Rapid Transport"
In SSTEC, the main modes of public transport are light rail transit (LRT), bus, and tramcar, within which only the LRT is mass rapid transport. Therefore, its evaluation of the indicator "main form of mass rapid transport" is 0.

③ "Main freight transport modes"
According to transport planning, the main freight transport mode in SSTEC is only road transportation. Hence, the evaluation of this indicator is -2.

(3) Energy

① "Main sources of energy supply"
Except basic energy supply from power grid, gas network and heating network, SSTEC has several auxiliary energy sources, including renewable energy, waste heat and co-generation. In accordance with its planning, at least 20% of the Eco-city's energy source should be from renewable energy. Waste heat from Beitang thermal power plant and Beijiang thermal power plant could meet 74.5% of the heating demand in SSTEC. The electricity production capacity of the co-generation system in the Eco-city is 1500kW, which meets 0.6% of the total electricity consumption, while also meeting 3% of the heating need. Consequently, its evaluation of indicator "main sources of energy supply" is +2.

Table 5.1 LCISS evaluation of SSTEC in Scale 1

First-class indicator	Second-class indicator	Third-class indicator		Weight	Value				
					-2	-1	0	+1	+2
Urban design	Site planning	1	Original land use type	0.0131	Arable land / woodland / grassland		Unused land		Brownfield
		2	Disaster risk	0.0653	There are constructions in high risk areas that threated by disasters, such as flood, geologic hazard, and secondary disaster				There is no construction in high risk areas that threated by disasters, geologic hazard, or secondary disaster.
	Land use	3	Mixture of functions	0.1567	D<0.980	0.980≤D≤0.988	D=0.990	0.992≤D≤0.994	0.995≤D
	Accessibility	4	Regional traffic connection	0.3134	No regional traffic connection	Partial regional traffic connection	Area wide regional traffic connection only by individual transport	Area wide regional traffic connection by individual transport and one kind of public transport	Area wide regional traffic connection by individual transport and various public transport
Transport	Motorized individual transport	5	Position in highway network	0.0395	Long distance (≥ 5km) to the next	Next highway < 5km away from the	Next highway < 2km away from the	Next highway < 1km away from the	Highway inside of the area, or along of a

					highway	border	border	border	border
	Public transport	6	Main form of Mass Rapid Transport	0.1298	No public transport connection	No MRT, only bus connection	LRT/BRT	Metro + LRT/BRT	Metro + LRT/BRT + commuter rail
	Freight transport	7	Main freight transport modes	0.0716	Road transportation is the only mode		Rail-road or port-road is the main mode		Port-road-rail is the main mode
Energy	Supply-side	8	Main sources of energy supply	0.2106	Conventional energy supply (power grid, gas network, heating network)		One auxiliary energy source (e.g. waste heat, renewable energy, co-generation, etc.) besides conventional energy system		More than one auxiliary energy sources (e.g. waste heat, renewable energy, co-generation, etc.) besides conventional energy system

5.4.2 LCISS Evaluation of Sino-Singapore Tianjin Eco-City in Scale 2

(1) Urban Design

① “Original land use type”
As discussed in 5.4.1, the evaluation of this indicator is 0 (see page 155).

② “Disaster risk”
As discussed in 5.4.1, the evaluation of this indicator is +2 (see page 155).

③ “Mixture of functions”
As discussed in 5.4.1, the evaluation of this indicator is +2 (see page 155).

④ “Urban development land area per capita”
SSTEC has 25.4km^2 construction areas, and a planned population of 350000. Subsequently, its urban development land area per capita is 72.57m^2 per capita that is lower than the planning standard of urban development per capita of new city (town) is 85.1 ~ 105.0m^2 per capita. This allocation of per capita urban development land could result in more compact urban structure and more efficient use of urban land. Thereby, the Eco-city receives +2 of this indicator.

⑤ “Small-scale block”
According to the planning, SSTEC is composed by “eco-cells”, the 400 by 400m basic city blocks. This scale is larger than the definition of a small-scale block in LCISS that has a side length of 150-200m. Based on the information obtained by interviewing with local experts, the percentage of blocks which meet the LCISS requirement is less than 40%. Hence, the Eco-city’s evaluation of this indicator is -2.

⑥ “Regional traffic connection”
As discussed in 5.4.1, the evaluation of this indicator is +2 (see page 156).

⑦ “Transit-oriented employment density”
In light of the planning, there are 190000 planned employments in SSTEC. As aforementioned, more than 90% of the Eco-city’s employments are concentrated within 500m of public transport hubs (Figure 5.2). Thereby, the evaluation of “transit-oriented employment density” is +2.

⑧ “Transit-oriented residential density”
Based on the information obtained from interview with local experts, the average residential floor area ratio (FAR) is 1.41, while within 500m of public transport hubs the residential FAR is 1.8-2, which is obviously higher than average. Therefore, SSTEC’s evaluation of “transit-oriented residential density” is +2.

⑨ “Greenery coverage ratio”
In accordance with the planning, the greenery coverage ratio of the Eco-city is 50%. Thus, its evaluation of this indicator is +2.

⑩ “Coverage ratio of green space service radius”
In light of the green space system planning, all residential areas in the Eco-city should have access to a Community Park within a walking distance of 500m. There are 16 planned community parks in SSTEC, and all parks shall be larger than $10000m^2$. Accordingly, an evaluation of +2 is given on the indicator “coverage ratio of green space service radius”.

(2) Transport

① “Road network density”
The total road length of SSTEC is 95.7km, including 39.5km main road, and 56.2km branch road that accounts for a higher proportion of the total length of network. The density of road network is $3.19km/km^2$. It is much higher than the national standard of “Code for transport planning on urban road (GB50220—95)” and also higher than the road network density in Tianjin ($1.244\ km/km^2$) (Tianjin Planning Bureau 2013).

② “Connection to the major origins and destinations”
In accordance with the planning, the entire area of the Eco-city has access to bus/tramcar station within the service radius of 500m. In turn, all of the major origins and destinations are connected by bus/tramcars. Additionally, the LRT Z4 line provides connection to most public service facilities. Thereby, it meets the evaluation of +1 of this indicator.

③ “Transit station coverage”
Since the entire area of the Eco-city has access to a bus/tramcar station within the service radius of 500m, SSTEC’s evaluation of this indicator is +2.

④ “Connectivity of footpaths”
According to the planning, SSTEC’s non-motorized transport system is characterized by high network density, separating motor and non-motor, and linking communities with main public facilities and public transport (tram/bus) stops. Hence, its evaluation of the indicator “connectivity of footpaths” is +2.

⑤ “Connectivity of cycle tracks”
According to the planning, SSTEC’s non-motorized transport system is characterized by high network density, separating motor and non-motor, and linking communities with main public facilities and public transport (tram/bus) stops. Hence, its evaluation of indicator “connectivity of cycle tracks” is +2.

(3) Energy

① “Main sources of energy supply”
As discussed in 5.4.1, the evaluation of this indicator is +2 (see page 158).

② “Renewable energy production”
In accordance with SSTEC’s master plan and KPIs, at least 20% of the Eco-city’s energy consumption should be from renewable energy, such as solar, wind, and geothermal energy. Thus, its evaluation of this indicator is +2.

③ “Electricity production by co-generation”
It is planned to construct 2 distributed power plants with co-generation systems: Tianjin Beijiang Combined Heat and Power (CHP) plant and Tianjin Beitang CHP plant. Their electricity production capacity is 1500kW that meets 0.6% of the total electricity consumption. Consequently, its evaluation of this indicator is 0.

(4) Building

① “Qualification ratio of building energy efficiency in new buildings”
In light of the planning, there are no existing buildings in the Eco-city. All new buildings should strictly implement the national standard of building energy efficiency. Thus, its qualification ratio of building energy efficiency in new buildings is 100%, so it receives +2.

② “Proportion of green buildings in new buildings”
According to the KPIs, all buildings in the Eco-city should meet the “Green building design standard for Sino-Singapore Tianjin Eco-city (DB29-195-2010)” (Sino-Singapore Tianjin Eco-City Administrative Committee 2010), which has more strict standards than the national standard of “Evaluation Standard for Green Building (GB-T50378 2014)”. Therefore, the proportion of green buildings in SSTEC is 100%, and it receives an evaluation on +2 of this indicator.

(5) Water

① “Water supply from non-traditional sources”
As planned and required in the KPIs, at least 50% of SSTEC’s water supply should be from non-traditional sources, such as recycled water, harvested stormwater, desalinated seawater, etc. Accordingly, the evaluation of indicator “water supply from non-traditional sources” is +2.

② “Treatment rate of wastewater”
SSTEC is expected to produce 76000m^3/day of wastewater. The wastewater will be collected and transferred to the Hangu Yingcheng wastewater treatment plant that its treatment capacity is 150000m^3/day. Hence, 100% of the wastewater in the Eco-city will be treated. The evaluation of this indicator is +2.

③ “Stormwater and wastewater diversion”
In accordance with the planning, stormwater and wastewater is collected in separate dedicated systems in SSTEC. Stormwater will be directly reused when possible and/or discharged into water bodies. Thereby, the evaluation of indicator of “stormwater and wastewater diversion” is +2.

④ “Drainage system”
Based on the information obtained from interview with local experts, the construction of the drainage system in SSTEC strictly implements the Code for Design of Outdoor Wastewater Engineering (GB50014-2006). Thus, the evaluation of indicator “drainage system” is 0.

⑤ “Flood prevention”
Based on the information obtained by interviewing with local experts, the construction of flood control facilities in SSTEC strictly implements the Code for Design of Urban Flood Control Project (GB/T50805-2012). Thus, the evaluation of indicator “flood prevention” is 0.

(6) Municipal solid waste

① “Waste collection rate”
Based on the data obtained from interviews with local experts, the waste collection rate in the Eco-city is 100%. Then, the evaluation of this indicator is +2.

② “Landfilling rate”
As planned and required in the KPIs, at least 60% of total waste should be recycled in SSTEC. After recycling, the remaining waste will be sent to the Binhai New Area (Hangu) waste incineration power plant outside the Eco-city for disposal. The waste and/or residue from all other processes will be transferred to Hangu landfill outside the Eco-city. Therefore, there is actually no waste landfilling in SSTEC. Its evaluation of indicator “landfilling rate” is +2.

③ “Harmless treatment rate”
In light of the KPIs, 100% of waste in SSTEC should receive harmless treatment. This indicator is actually already achieved, since all waste in the Binhai New Area is being rendered harmless treatment. Thus, the Eco-city’s evaluation of indicator “harmless treatment rate” is +2.

Table 5.2 LCISS evaluation of SSTEC in Scale 2

First-class indicators	Second-class indicators	Third-class indicators		Weight	Value				
					-2	-1	0	+1	+2
Urban design	Site planning	1	Original land use type	0.0025	Arable land / woodland / grassland		Unused land		Brownfield
		2	Disaster risk	0.0125	There are constructions in high risk areas that threated by disasters, such as flood, geologic hazard, and secondary disaster				There is no construction in high risk areas that threated by disasters, geologic hazard, or secondary disaster.
	Land use	3	Mixture of functions	0.0082	D<0.980	0.980≤D≤0.988	D=0.990	0.992≤D≤0.994	0.995≤D
		4	Urban development land area per capita	0.0130	Higher than the standard stated in the PRC's National Standard GB 50137-2011		Compliance with the standard stated in the PRC's National Standard GB 50137-2011		Lower than the standard stated in the PRC's National Standard GB 50137-2011
		5	Small-scale block	0.0205	R<40%	40%≤R<50%	50%≤R<70%	70%≤R<80%	80%≤R
	Accessibility	6	Regional traffic connection	0.0059	No regional traffic connection	Partial regional traffic	Area wide regional traffic	Area wide regional traffic	Area wide regional traffic

						connection	connection only by individual transport	connection by individual transport and one kind of public transport	connection by individual transport and various public transport
		7	Transit-oriented employment density	0.0145	Lowest density of the area at public transport hubs	Density slightly below average	Average density of the area	Density slightly above average	Highest density of the area at public transport hubs
		8	Transit-oriented residential density	0.0092	Lowest density of the area at public transport hubs	Density slightly below average	Average density of the area	Density slightly above average	Highest density of the area at public transport hubs
	Green open space	9	Greenery coverage ratio	0.0107	>20% than the average level	≤20% below the average level	Similar like the average level	≤20% above the average level	>20% above the average level
		10	Coverage ratio of green space service radius	0.0107	R<60%	60%≤R<70 %	70%≤R<80 %	80%≤R<90 %	90%≤R
Transport	Motorized individual transport	11	Road network density	0.0404	Below the standard, and branch roads account lower proportion of total length of network	Below the standard	Complies with Standard	Above the standard	Above the standard, and branch roads account higher proportion of total length of network
	Public transport	12	Connection to the major origins and destinations	0.0292	No connection,	Bus connection	Bus connection	MRT connection	MRT connection

					or only bus connection to some of the major origins and destinations	to the most of major origins and destinations	to all major origins and destinations	to the most of major origins and destinations, bus connection to the remaining origins and destinations	to all major origins and destinations
		13	Transit station coverage	0.1169	<45% (urban area); <63% (city center area)		45%-50% (urban area); 63%-70% (city center area)		>50% (urban area); >70% (city center area)
	Non-motorized transport	14	Connectivity of footpaths	0.0148	Area is not complete equipped with foot paths along the streets	Area is nearly complete equipped with foot paths along the streets	Area has footpaths separated from the streets	Short & direct footpaths connect to major facilities	Footpaths link to various grades of highway in surrounding areas
		15	Connectivity of cycle tracks	0.0296	Area is not complete equipped with cycle tracks	Area is nearly complete equipped with cycle tracks along the roads	Area has cycle tracks separated from the roads	Short & direct cycle tracks connect to major facilities	Cycle tracks link to various grades of highway in surrounding areas
Energy	Supply-side	16	Main sources of energy supply	0.1272	Conventional energy supply (power grid, gas network,		One auxiliary energy source (e.g. waste heat,		More than one auxiliary energy sources (e.g. waste heat,

					heating network)		renewable energy, co-generation, etc.) besides conventional energy system		renewable energy, co-generation, etc.) besides conventional energy system
		17	Renewable energy production	0.0809	R<5%	5%≤R<10%	10%≤R<15%	15%≤R<20%	20%≤R
		18	Electricity production by co-generation	0.0513	R=0		0<R<5%		5%≤R
Building	New buildings	19	Qualification ratio of building energy efficiency in new buildings	0.0536	R<95%		95%≤R<100%		R=100%
		20	Proportion of green buildings in new buildings	0.0536	R<5%	5%≤R<20%	20%≤R<35%	35%≤R<50%	50%≤R
Water	Water supply	21	Water supply from non-traditional sources	0.0770	R<5%	5%≤R<10%	10%≤R<15%	15%≤R<20%	20%≤R
	Wastewater treatment	22	Treatment rate of wastewater	0.0770	>10% than the average level	≤10% below the average level	Similar like the average level	≤10% above the average level	>10% above the average level
	Stormwater management	23	Stormwater and wastewater diversion	0.0120	R<100%				R=100%
		24	Drainage system	0.0076	Not meet the "Code for Design of Outdoor Wastewater"		Meet the "Code for Design of Outdoor Wastewater"		Above the "Code for Design of Outdoor Wastewater"
		25	Flood prevention	0.0189	Not meet the "Code for Design of Urban Flood Control		Meet the "Code for Design of Urban Flood Control		Above the "Code for Design of Urban Flood Control

					Project”		Project”		Project”
MSW	MSW collection & transfer	26	Waste collection rate	0.0682	R<70%	70%≤R<80	80%≤R<90 %	90%≤R<100 %	R=100%
	MSW disposal	27	Landfilling rate	0.0085	>10% above the average level	≤10% above the average level	Similar like the average level	≤10% below the average level	>10% below the average level
		28	Harmless treatment rate	0.0256	>5% below the average level	≤5% below the average level	Similar like the average level	≤5% above the average level	>5% above the average level

5.4.3 LCISS evaluation of Sino-Singapore Tianjin Eco-City in Scale 3

(1) Urban design

① "Original land use type"
As discussed in 5.4.1, the evaluation of this indicator is 0 (see page 155).

② "Mixture of functions"
As discussed in 5.4.1, the evaluation of this indicator is +2 (see page 155).

③ "Urban development land area per capita"
As discussed in 5.4.2, the evaluation of this indicator is +2 (see page 161).

④ "Small-scale block"
As discussed in 5.4.2, the evaluation of this indicator is -2 (see page 161).

⑤ "Regional traffic connection"
As discussed in 5.4.1, the evaluation of this indicator is +2 (see page 156).

⑥ "Transit-oriented employment density"
As discussed in 5.4.2, the evaluation of this indicator is +2 (see page 161).

⑦ "Transit-oriented residential density"
As discussed in 5.4.2, the evaluation of this indicator is +2 (see page 161).

⑧ "Greenery coverage ratio"
As discussed in 5.4.2, the evaluation of this indicator is +2 (see page 162).

⑨ "Coverage ratio of green space service radius"
As discussed in 5.4.2, the evaluation of this indicator is +2 (see page 162).

⑩ "Quality of green open space"
Based on the information obtained from interviews with local experts, green open spaces in the Eco-city are well-equipped with various public facilities in order to meet the recreational need of residents. In addition, the distribution of green open space is integrated with a non-motorized transport system, thus most green open spaces are well arranged and accessible. Moreover, because of the soil salinization, to ensure the survival rate of vegetation, native plants are widely planted in green open spaces in the Eco-city. Consequently, three criteria from the indicator of "quality of green open space" are fulfilled by most green open spaces, including: i) equipped with various public facilities (e.g. furniture, sculpture, landscape decoration, and fountain); ii) plant low water consumption native plants; iii) good accessibility. The evaluation of this indicator is 0.

(2) Transport

① "Car park management"

According to the master plan, SSTEC planned to build 17 car parks, with a total area of 66000m^2, having 120000 parking spaces. Of the 17 car parks, there are 11 "Park and Ride" parks[32] placed around road entrances/exits on the outer edges of the Eco-city, and 6 public car parks surrounded commercial centers. Although the master plan has clearly defined the number and allocation of parking spaces and types of parking (e.g. a ban of on-street parking), but policy for car park management is still not developed in the Eco-city. Thus, the evaluation of indicator "car park management" receives -2.

② "Recharging devices of E-mobility"

According to the planning, recharging devices of E-mobility should be equipped in all parking spaces of SSTEC, but allocation and number is not clearly defined. Based on field study, recharging devices are only equipped in some public parking spaces. Hence, the Eco-city's evaluation of this indicator is 0.

③ "Car sharing"

Based on the information obtained from interviews with local experts, three criteria from the indicator "car sharing" are fulfilled by the car sharing service in SSTEC: i) easy registration and payment; ii) online reservation; iii) various types of vehicles (cars and trucks). Thus, it receives +1 on this indicator.

④ "Prioritization for low emission vehicles"

In 2014, Tianjin has issued the regulation for new energy vehicles subsidy. Since SSTEC is a project located in Tianjin, the regulation is also implemented in the Eco-city that fulfills the criterion "subsidies and tax concessions to encourage the purchase and use of low emission vehicles" of the indicator "prioritization for low emission vehicles". Besides that, there is no other incentive to promote the use of low emission vehicles. Subsequently, the evaluation of this indicator is -1.

⑤ "Velocity of public transport"

Based on the data obtained from interviews with local experts, in the Eco-city, the present ratio of committing time by public transport to commuting time by auto during peak hours is 1:1. As planned, bus lanes of primary roads and LRT line should be built by 2020. Then this ratio will be 1:1.2. Hence, the evaluation of indicator "velocity of public transport" is +2.

⑥ "Average wait-time in the highest peak hour"

Based on field study and information obtained from interviews with local experts, at main home and work areas of the Eco-city, the average wait-time of public transport during peak hours is ca. 5 minutes. Then, its evaluation of this indicator is +1.

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[32] Park and Ride (P&R) park refers to car park with connections to public transport services, allowing people heading to city centers to complete their journey by bus or rail system.

⑦ “Emission level of buses”

Since 1st Sept. 2015, the National Discharge Standard of Vehicle Pollutant (Ⅴ Stage) is enforced on all buses in Tianjin. As a project located in Tianjin, SSTEC has also implemented this standard. Accordingly, its evaluation of indicator “emission level of buses” is +2.

⑧ “Quality of public transport vehicles”

On the basis of field study and information obtained from interview with local experts, all buses in SSTEC are equipped with air-conditioner, real-time passenger information device, wide doors, and TVs. It meets all criteria of indicator “quality of public transport vehicles”, and therefore receives +2.

⑨ “Quality of public transport stations”

Based on field study and information obtained from interviews with local experts, all public transport stations in SSTEC are equipped with a canopy (excl. temporary stations), lighting facilities, barrier-free facilities, and passenger information systems. It fulfills four criteria of indicator “quality of public transport stations”: i) canopy; ii) passenger travel information; iii) lighting; iv) barrier-free access. The evaluation of this indicator is 0.

⑩ “Quality of footpaths”

In light of the transport planning, the Eco-city has a specific non-motorized transport lane system separating it from motorways. Footpaths, as planned, should be no less than 3m in width, well-paved, and with green space and furniture. Then its evaluation of indicator “quality of footpaths” is 0.

⑪ “Quality of cycle tracks”

In light of the transport planning, the Eco-city has a specific non-motorized transport lane system separating it from motorways. Cycle tracks, as planned, should be well paved, and with green space and furniture. The width of one-way cycle tracks should be no less than 2m, and the width of two-way cycle tracks should be no less than 6m. Its evaluation of indicator “quality of cycle tracks” is 0.

⑫ “Non-motorized vehicle parking”

According to the planning, sufficient non-motorized vehicle parking spaces should be available around important urban public facilities in the Eco-city, and all parking spaces should have bicycle racks, lighting facilities, clear signage, and security systems. It fulfills all criteria of the indicator “non-motorized vehicle parking”, and then receives +2.

⑬ “Prioritization for low emission trucks”

In 2014, Tianjin issued the regulation for new energy vehicles subsidy. Since SSTEC is a project located in Tianjin, the regulation is also implemented in the Eco-city that fulfills the criterion “subsidies and tax concessions to encourage the purchase and use of low emission vehicles" of indicator "prioritization for low emission trucks". Besides that, there is no other incentive to promote the use of low emission trucks. Subsequently, the evaluation of this indicator is -1.

(3) Energy

① "Main sources of energy supply"
As discussed in 5.4.1, the evaluation of this indicator is +2 (see page 158).

② "Renewable energy production"
As discussed in 5.4.2, the evaluation of this indicator is +2 (see page 163).

③ "Electricity production by co-generation"
As discussed in 5.4.2, the evaluation of this indicator is 0 (see page 163).

④ "Green electricity contract"
On the basis of the information obtained from interviews with local experts, there is no green electricity program implemented in SSTEC. Thus, its evaluation of indicator "green electricity contract" is -2.

⑤ "Incentive policy of renewable energy utilization"
In 2012, the Ministry of Housing and Urban-Rural Development and Ministry of finance had allocated ¥500 million special renewable energy funds for promoting the utilization of renewable energy in SSTEC. Accordingly, the evaluation of indicator "incentive policy of renewable energy utilization" is +2.

⑥ "Metered heating rate"
As explicitly stipulated in the planning, all residential buildings and public buildings in the Eco-city should be equipped with a heating meter for individual units/tenants and being billed by the meter. Thus, its metered heating rate is 100%, and it receives +2.

(4) Building

① "Qualification ratio of building energy efficiency in new buildings"
As discussed in 5.4.2, the evaluation of this indicator is +2 (see page 163).

② "Proportion of green buildings in new buildings"
As discussed in 5.4.2, the evaluation of this indicator is +2 (see page 163).

(5) Water

① "Water supply from non-traditional sources"
As discussed in 5.4.2, the evaluation of this indicator is +2 (see page 163).

② "Water tariff"
Based on the information obtained from interviews with local experts, the IBT system is not established or planned to implement in SSTEC. Additionally, the current water tariffs of the Eco-city cannot cover the real costs associated with water production, distribution, and wastewater collection and treatment. Then, the evaluation of indicator "water tariff" is -2.

③ "Leakage rate"
As stipulated in SSTEC's planning, the leakage rate of the water supply pipe network should be less than 10%. In fact, according to the data obtained from interviews with local experts, the real leakage rate of the Eco-city is 7.6%. Hence, it receives +2 of indicator "leakage rate".

④ "Coverage of water-saving appliances"
The implementation of water-saving appliances is a mandatory requirement of the "Green building design standard for Sino-Singapore Tianjin Eco-city (DB29-195-2010)". As explained in 5.4.2, the green building code should be applied in all buildings in the Eco-city, thus, the coverage of water-saving appliances will also be 100%. The evaluation of this indicator is +2.

⑤ "Treatment rate of wastewater"
As discussed in 5.4.2, the evaluation of this indicator is +2 (see page 163).

⑥ "Stormwater and wastewater diversion"
As discussed in 5.4.2, the evaluation of this indicator is +2 (see page 164).

⑦ "Drainage system"
As discussed in 5.4.2, the evaluation of this indicator is 0 (see page 164).

⑧ "Flood prevention"
As discussed in 5.4.2, the evaluation of this indicator is 0 (see page 164).

(6) Municipal solid waste

① "Waste collection rate"
As discussed in 5.4.2, the evaluation of this indicator is +2 (see page 164).

② "Proportion of communities with separate waste collection facilities"
In accordance with the waste management planning, a full-coverage waste sorting and recycling system will be established in the Eco-city that separate waste collection facilities should be implemented in all communities and public buildings. By 2020, the source separation rate of waste in SSTEC will be no less than 85%. Consequently, the evaluation of indicator "proportion of communities with separate waste collection facilities" is +2.

③ “Waste transport vehicle”

According to the information obtained from interviews with local experts, currently most waste transport vehicles of the Eco-city meet the National Discharge Standard of Vehicle Pollutant (Ⅳ Stage). Thereby, its evaluation of indicator “waste transport vehicle” is +1.

④ “Landfilling rate”

As discussed in 5.4.2, the evaluation of this indicator is +2 (see page 164).

⑤ “Harmless treatment rate”

As discussed in 5.4.2, the evaluation of this indicator is +2 (see page 164).

Table 5.3 LCISS evaluation of SSTEC in Scale 3

First-class indicators	Second-class indicators	Third-class indicators		Weight	Value				
					-2	-1	0	+1	+2
Urban design	Site planning	1	Original land use type	0.0098	Arable land / woodland / grassland		Unused land		Brownfield
	Land use	2	Mixture of functions	0.0071	D<0.980	0.980≤D≤0.988	D=0.990	0.992≤D≤0.994	0.995≤D
		3	Urban development land area per capita	0.0062	Higher than the standard stated in the PRC's National Standard GB 50137-2011		Compliance with the standard stated in the PRC's National Standard GB 50137-2011		Lower than the standard stated in the PRC's National Standard GB 50137-2011
		4	Small-scale block	0.0162	R<40%	40%≤R<50%	50%≤R<70%	70%≤R<80%	80%≤R
	Accessibility	5	Regional traffic connection	0.0031	No regional traffic connection	Partial regional traffic connection	Area wide regional traffic connection only by individual transport	Area wide regional traffic connection by individual transport and one kind of public transport	Area wide regional traffic connection by individual transport and various public transport
		6	Transit-oriented employment density	0.0100	Lowest density of the area at public transport hubs	Density slightly below average	Average density of the area	Density slightly above average	Highest density of the area at public transport hubs

		7	Transit-oriented residential density	0.0055	Lowest density of the area at public transport hubs	Density slightly below average	Average density of the area	Density slightly above average	Highest density of the area at public transport hubs
	Green open space	8	Greenery coverage ratio	0.0041	>20% than the average level	≤20% below the average level	Similar like the average level	≤20% above the average level	>20% above the average level
		9	Coverage ratio of green space service radius	0.0051	R<60%	60%≤R<70 %	70%≤R<80 %	80%≤R<90 %	90%≤R
		10	Quality of green open space: 1. Equipped with various public facilities (e.g. furniture, sculpture, landscape decoration, fountain) 2.Plant low water consumption native plants 3.Well functional organized space with different uses 4.Good accessibility 5.Bright lights at key locations 6.Clear signage 7.Well shadowed 8. Applied devices by renewable energy 9. Applied light colored, durable, environmental friendly pavement material	0.0032	No one criterion fulfilled	1-2 criterion fulfilled	3-4 criteria fulfilled	5-6 criteria fulfilled	All criteria fulfilled
Transport	Motorized	11	Car park management	0.0073	No local law,		Local laws,		Local laws,

	individual transport				regulation and policy of car park management		regulations and policies of car park management are being developed		regulations and policies of car park management have been implemented
		12	Recharging devices of E-mobility	0.0050	No recharging device	Some parking with recharging devices, access only for employee of some companies, private garage owners, or parking pass holders	Some parking with recharging devices, access for all	Adequate number of parking with recharging devices, access for all	Adequate number of parking with recharging devices, access for all; and combined with transport connection point, easy payment
		13	Car sharing: 1. Cars available in the whole area - not station-bounded 2.Easy registration and payment 3.Online reservation 4. Discount on public transport tickets 5. Various types of vehicles (cars and trucks)	0.0050	No car sharing concept	Car sharing available but no one criterion fulfilled	1 criteria fulfilled	2-3 criteria fulfilled	4 or more criteria fulfilled
		14	Prioritization for low emission vehicles: 1. Subsidies and tax concessions to encourage	0.0072	No one criterion fulfilled	1 criteria fulfilled	2 criteria fulfilled	3 criteria fulfilled	All criteria fulfilled

			the purchase and use of low emission vehicles 2. Permission to enter auto restricted zones 3. No traffic restriction (odd-and-even number limit lines) 4. Parking charge discount						
	Public transport	15	Velocity of public transport	0.0428	R>2.5	2<R≤2.5	1.5<R≤2	1<R≤1.5	R≤1
		16	Average wait-time in the highest peak hour	0.0173	>20mins	11-20mins	6-10mins	3-5mins	<3mins
		17	Emission level of buses	0.0102	Most vehicles meet the National Discharge Standard of Vehicle Pollutant (Ⅰ Stage)	Most vehicles meet the National Discharge Standard of Vehicle Pollutant (Ⅱ Stage)	Most vehicles meet the National Discharge Standard of Vehicle Pollutant (Ⅲ Stage)	Most vehicles meet the National Discharge Standard of Vehicle Pollutant (Ⅳ Stage)	Most vehicles meet the National Discharge Standard of Vehicle Pollutant (Ⅴ Stage)
		18	Quality of vehicles of public transport: 1. Air-conditions 2. Wide doors 3. Passenger travel information 4. Entertainments (e.g. TV, internet service)	0.0099	Most of vehicles do not fulfill any criterion	1 criterion fulfilled by most vehicles	2 criteria fulfilled by the most of vehicles	3 criteria fulfilled by the most of vehicles	All criteria fulfilled by the most of vehicles
		19	Quality of public transport stations: 1. Canopy 2. Ticket machine 3. Passenger travel information	0.0112	Most of stations don't fulfill any criterion	1-2 criteria fulfilled for the most of stations	3-4 criteria fulfilled for the most of stations	5-6 criteria fulfilled for the most of stations	All criteria fulfilled for the most of stations

			4. Lighting 5. Barrier-free access 6. Bicycle parking infrastructure 7. Small scale shopping possibility nearby						
	Non-motorized transport	20	Quality of footpaths	0.0207	Footpaths are too narrow (<2m), barely usable	Footpaths have usable width (≥ 2m)	Footpaths have usable width (≥ 2m); and separated from motorways; most footpaths are smooth, well-lighted, furnished, greened	Footpaths have sufficient width (large city ≥6m; small and medium-sized cities ≥4m) and separation from motorways	Footpaths have sufficient width (large city ≥6m; small and medium-sized cities ≥4m) and separation from motorways; most footpaths are well-paved, well-lighted, furnished, greened
		21	Quality of cycle tracks	0.0132	Tracks are too narrow (one-way W<2m; two-way W<2.4m), barely usable	Tracks have usable width (one-way 2m≤W<4m; two-way 2.4m≤W<6 m)	Tracks have usable width (one-way 2m≤W<4m; two-way 2.4m≤W<6 m); and separated from motorways;	Tracks have sufficient width (one-way 4m≤W; two-way 6m≤W) and separation from motorways	Tracks have sufficient width (one-way 4m≤W; two-way 6m≤W) and separation from motorways;

							most tracks are well-paved, well-lighted, furnished, greened		most tracks are well-paved, well-lighted, furnished, greened
		22	Non-motorized vehicle parking: 1.Sufficient parking space at important public service facilities and PT stops 2.Well-equipped bicycle racks and lighting 3.Good security 4.Clear signage	0.0083	Most of parks do not fulfill any criteria	1 or more criteria fulfilled by several parks	2 criteria fulfilled by the most of parks	3 criteria fulfilled by the most of parks	All criteria fulfilled by the most of parks
	Freight transport	23	Prioritization for low emission trucks: 1. Subsidies and tax concessions to encourage the purchase and use of low emission vehicles 2. Permission to enter auto restricted zones 3. No restriction for delivering time periods 4. Recharging devices in delivering zones 5. Special delivering zones only for low emission trucks	0.0304	No one criterion fulfilled	1 criterion fulfilled	2 criteria fulfilled	3 criteria fulfilled	All criteria fulfilled
Energy	Supply-side	24	Main sources of energy supply	0.1235	Conventional energy supply (power grid,		One auxiliary energy source (e.g.		More than one auxiliary energy sources (e.g.

					gas network, heating network)		waste heat, renewable energy, co-generation, etc.) besides conventional energy system		waste heat, renewable energy, co-generation, etc.) besides conventional energy system
		25	Renewable energy production	0.0553	R<5%	5%≤R<10%	10%≤R<15%	15%≤R<20%	20%≤R
		26	Electricity production by co-generation	0.0243	R=0		0<R<5%		5%≤R
	Demand-side	27	Green electricity contract	0.0124	No green electricity contract				Green electricity contract available
		28	Incentive policy of renewable energy utilization	0.0233	No clear incentive policy and plan		Incentive policies and plans are being developed		Incentive policies and plans have been implemented
		29	Metered heating rate	0.0658	R<10% (residential building); R<20% (public building)	10%≤R<15% (residential building); 20%≤R<30% (public building)	15%≤R<20% (residential building); 30%≤R<40% (public building)	20%≤R<25% (residential building); 40%≤R<50% (public building)	25%≤R (residential building); 50%≤R (public building)
Building	New buildings	30	Qualification ratio of building energy efficiency in new buildings	0.0776	R<95%		95%≤R<100%		R=100%
		31	Proportion of green buildings in new buildings	0.0776	R<5%	5%≤R<20%	20%≤R<35%	35%≤R<50%	50%≤R

Water	Water supply	32	Water supply from non-traditional sources	0.0142	R<5%	5%≤R<10%	10%≤R<15 %	15%≤R<20 %	20%≤R
		33	Water tariff	0.0061	Increasing block water tariff system not established, water price is lower than the cost	Increasing block water tariff system not established, water price is higher than the cost	Increasing block water tariff system established, water price is lower than the cost	Increasing block water tariff system established, water price is higher than the cost, charge rate cannot balance the payment	Increasing block water tariff system established, water price is higher than the cost, charge rate achieve low profit breakeven
		34	Leakage rate	0.0067	14%≤R	12%<R<14 %	R=12%	10%<R<12 %	R≤10%
		35	Coverage of water-saving appliances	0.0348	R<76%	76%≤R<84 %	84%≤R<92 %	92%≤R<100 %	R=100%
	Wastewater treatment	36	Treatment rate of wastewater	0.0706	>10% than the average level	≤10% below the average level	Similar like the average level	≤10% above the average level	>10% above the average level
	Stormwater management	37	Stormwater and wastewater diversion	0.0108	R<100%				R=100%
		38	Drainage system	0.0055	Not meet the "Code for Design of Outdoor Wastewater"		Meet the "Code for Design of Outdoor Wastewater"		Above the "Code for Design of Outdoor Wastewater"
		39	Flood prevention	0.0108	Not meet the "Code for Design of Urban Flood Control Project"		Meet the "Code for Design of Urban Flood Control Project"		Above the "Code for Design of Urban Flood Control Project"
MSW	MSW	40	Waste collection rate	0.0271	R<70%	70%≤R<80	80%≤R<90	90%≤R<100	R=100%

	collection & transfer						%	%	
		41	Proportion of communities with separate waste collection facilities	0.0426	R=0		0<R<15%		15%≤R
		42	Emission level of waste transport vehicles	0.0115	Most vehicles meet the national discharge standard of vehicle pollutant (Ⅰ Stage)	Most vehicles meet the national discharge standard of vehicle pollutant (Ⅱ Stage)	Most vehicles meet the national discharge standard of vehicle pollutant (Ⅲ Stage)	Most vehicles meet the national discharge standard of vehicle pollutant (Ⅳ Stage)	Most vehicles meet the national discharge standard of vehicle pollutant (Ⅴ Stage)
	MSW disposal	43	Landfilling rate	0.0102	>10% above the average level	≤10% above the average level	Similar like the average level	≤10% below the average level	>10% below the average level
		44	Harmless treatment rate	0.0305	>5% below the average level	≤5% below the average level	Similar like the average level	≤5% above the average level	>5% above the average level

5.5 Evaluation results

Given that SSTEC aims to become a practicable, replicable and scalable demonstration of eco and low-carbon city for other Chinese cities, the LCISS evaluation presents an opportunity to check SSTEC's plan in terms of its level of low-carbon development. As discussed in 4.1.4, the evaluation result of the LCISS consists of three products: evaluation checklist, evaluation report, and development guideline.

5.5.1 Evaluation checklist of Sino-Singapore Tianjin Eco-City

The evaluation checklists are shown in Table 5.1, Table 5.2 and Table 5.3. From this intuitional result, SSTEC has made some success in low-carbon development that its performance in most indicators is above the average, at the same time, its shortage is also clearly indicated by indicators with low scores.

5.5.2 Evaluation report of Sino-Singapore Tianjin Eco-City

According to the evaluation checklist, SSTEC's comprehensive values are calculated as +1.4278 in scale 1, +1.7282 in scale 2, and +1.4780 in scale 3, which shows that the Eco-city has a good low-carbon performance in all macro, middle and micro planning scales. In several key indicators, such as "greenery coverage ratio", "transit station coverage", "renewable energy production" and "proportion of green buildings in new buildings", it performs much better than the national average. Nevertheless, there are still some problems in management policies that the evaluation is scoring badly in indicators e.g. "car park management", "prioritization for low emission vehicles", "water tariff", etc. The analysis of specific performance in each evaluation sector is as follows:

Urban design

The urban design sector involves all three scales, and its weight is 0.5485 in scale 1, 0.1077 in scale 2, and 0.0703 in scale 3. It clearly shows that the role of this sector declined in the evaluation when the planning became more concrete and detailed. Without considering the weight of first-class indicators, the comprehensive value of the sector "urban design" is +1.9522 in scale 1, +1.1922 in scale 2, and +0.7084 in scale 3.

The evaluation of "urban design" includes four aspects: site planning, land use, accessibility and green open space. When only considering the relative important degree of three-class indicators, the evaluation values of all these aspects can be calculated.

- The evaluation value of "site planning" is +1.6667 in scale 1 and scale 2, and 0 in scale 3.

· The evaluation value of "land use" is +2 in scale 1, +0.038 in scale 2, and -0.1940 in scale 3.

· The evaluation value of "accessibility" is +2 in all three scales.

· The evaluation value of "green open space" is +2 in scale 2, and +1.4778 in scale 3.

As illustrated in Figure 5.5, the evaluation of this sector is generally good in most aspects, but could be optimized in "land use" in scale 3.

Figure 5.5 Evaluation result of urban design

Transport

The transport sector involves all three scales, and its weight is 0.2409 in scale 1, 0.2309 in scale 2, and 0.1885 in scale 3. The relative importance of this sector slightly declined in the evaluation when the planning became more concrete and detailed. Without considering the weight of first-class indicators, the comprehensive value of the transport sector is -0.2665 in scale 1, +1.8735 in scale 2, and +0.5968 in scale 3.

The evaluation of "transport" consists of four aspects: motorized individual transport, public transport, non-motorized transport and freight transport. When only considering the relatively important degree of three-class indicators, the evaluation values of all these aspects can be calculated.

· The evaluation value of "motorized individual transport" is +2 in scale 1 and scale 2, and -0.6901 in scale 3.

· The evaluation value of "public transport" is 0 in scale 1, +2 in scale 2, and +1.5652 in scale 3.

- The evaluation value of “non-motorized transport” is +2 in scale 2 and +0.3952 in scale 3.

- The evaluation value of “freight transport” is -2 in scale 1 and -1 in scale 3.

As illustrated in Figure 5.6, the evaluation of this sector is not ideal. Optimizations could be made in “motorized individual transport” in scale 3, and in “freight transport” in scale 1 and 3.

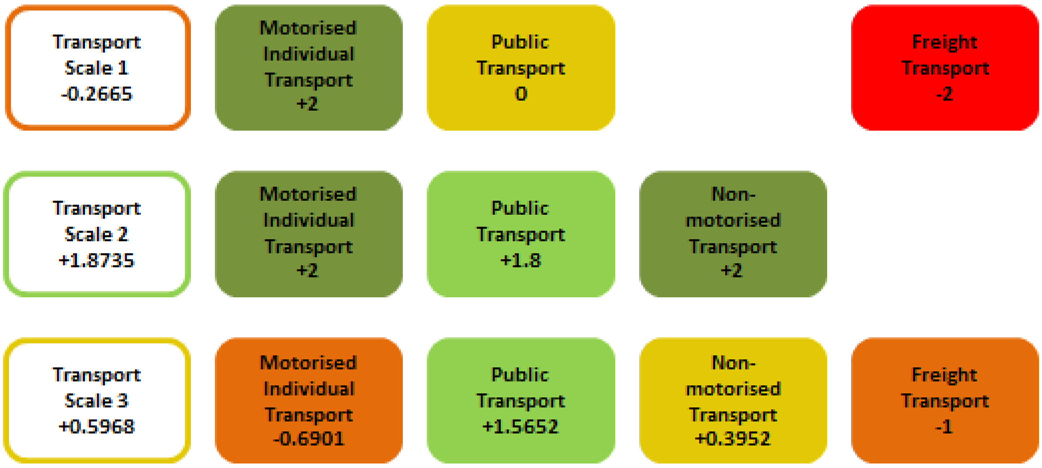

Figure 5.6 Evaluation result of transport

Energy

The energy sector involves all three scales, and its weight is 0.2106 in scale 1, 0.2594 in scale 2, and 0.3046 in scale 3. It is obvious that the relative importance of this sector increased when the planning became more concrete and detailed. Without considering the weight of first-class indicators, the comprehensive value of the energy sector is +2 in scale 1, +1.6045 in scale 2, and 1.6776 in scale 3.

The evaluation of “energy” consists of two aspects: supply-side and demand-side. When only considering the relatively important degree of three-class indicators, the evaluation values of all these aspects can be calculated.

- The evaluation value of “supply-side” is +2 in scale 1, +1.6048 in scale 2, and +1.7602 in scale 3.

- The evaluation value of “demand-side” is +1.5112 in scales 3.

As illustrated in Figure 5.7, the evaluation of the energy sector is generally good without obvious shortage.

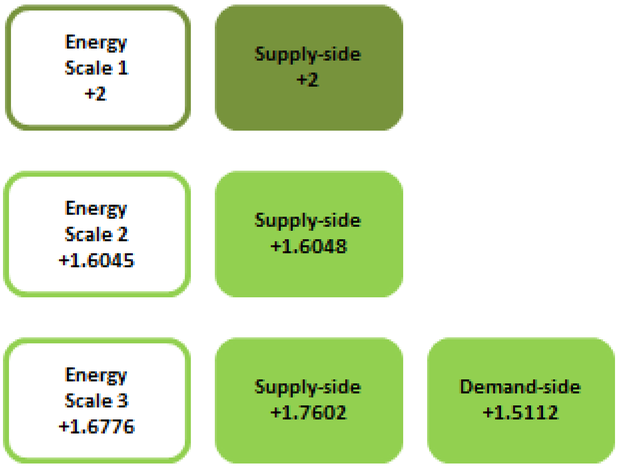

Figure 5.7 Evaluation result of energy

Building

The building sector covers scales 2 and 3, and its weight is 0.1072 in scale 2, and 0.1552 in scale 3. It is clear that the relative importance of this sector increased when the planning became more concrete and detailed. Without considering the weight of first-class indicators, the comprehensive value of the building sector is +2 in both scale 2 and scale 3.

SSTEC is a new town project, there are no existing buildings. Thus, only "new buildings" is involved in the evaluation of "building". When only considering the relative important degree of three-class indicators, the evaluation value of "new buildings" can be calculated that it is +2 in both scale 2 and scale 3.

As shown in Figure 5.8, the evaluation of the sector of energy is excellent that has been a highlight of SSTEC's low-carbon development.

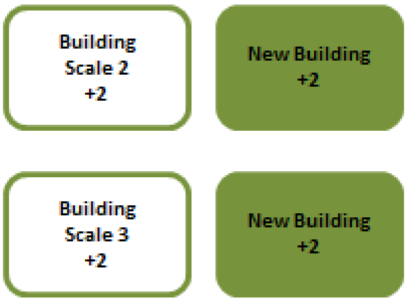

Figure 5.8 Evaluation result of building

Water

The water sector involves scales 2 and 3, and its weight is 0.1925 in scale 2, and 0.1595 in scale 3. The role of this sector declined in the evaluation when the planning became more concrete and detailed. Without considering the weight of first-class indicators, the comprehensive value of the sector "water" is +1.7247 in scale 2 and +1.6426 in scale 3.

The evaluation of "water" focuses on three aspects: water supply, wastewater treatment and stormwater management. When only considering the relative important degree of three-class indicators, the evaluation values of all these aspects can be calculated.

- The evaluation value of "water supply" is +2 in scale 2 and +1.6044 in scale 3.
- The evaluation value of "wastewater treatment" is +2 in both scale 2 and scale 3.
- The evaluation value of "stormwater management" is +0.6238 in scale 2 and +0.8 in scale 3.

As illustrated in Figure 5.9, the evaluation of this sector is generally good without obvious shortage.

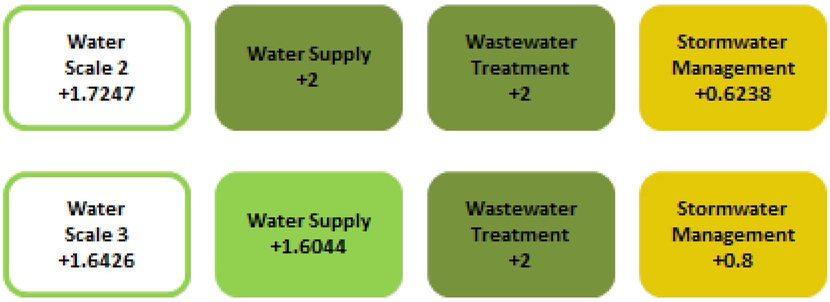

Figure 5.9 Evaluation result of water

Municipal solid waste

The municipal solid waste (MSW) sector involves scales 2 and 3, and its weight is 0.1023 in scale 2, and 0.1219 in scale 3. The relative importance of this sector increased slightly when the planning became more concrete and detailed. Without considering the weight of first-class indicators, the comprehensive value of the sector of MSW is +2 in scale 2 and +1.9057 in scale 3.

The evaluation of "MSW" consists of two aspects: MSW collection & transfer, and MSW disposal. When only considering the relative important degree of three-class indicators, the evaluation values of all these aspects can be calculated.

- The evaluation value of "MSW collection & transfer" is +2 in scale 2 and +1.8585 in scale 3.
- The evaluation value of "MSW disposal" is +2 in both scale 2 and scale 3.

As seen in Figure 5.10, the evaluation of this sector is generally good without obvious shortages.

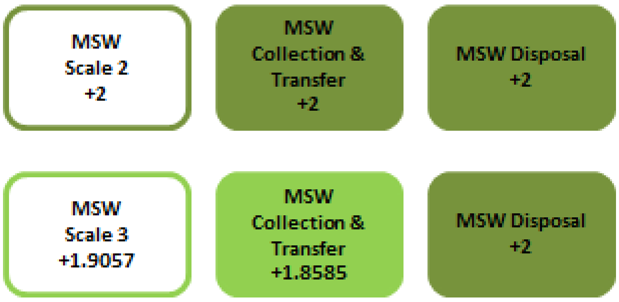

Figure 5.10 Evaluation result of MSW

Based on the analysis above, SSTEC's low-carbon development problems mainly focus on the urban design and transport sector (Figure 5.11), including:

- SSTEC is composed of "eco-cells", the 400 by 400m basic city blocks, which accommodates 8000 residents. This scale has greatly surpassed the size of "small-scale block" with a side length of 150-200m. Based on the larger blocks, the road network is designed without smaller road networks within blocks, which may lead people to lose interest in walking and cycling, and also keep public transport off the block, this partly encourages people to use private cars. In addition, great deals of traffic flows from the exits of blocks converging at main roads at peak hours, this causes traffic congestion, and more energy consumption and CO_2 and exhaust emissions.

- SSTEC planned to build 17 car parks, with a total area of 66000m^2, having 120000 parking spaces. Of the 17 car parks, there are 11 "Park and Ride" parks[33] placed around road entrances/exits on the outer edges of the Eco-city, and 6 public car parks surrounding commercial centers. Although the master plan has clearly defined the number and allocation of parking spaces and types of parking (e.g. a ban of on-street parking), but policy for car park management is still not developed in the Eco-city. Since policies impacting parking availability and costs will significantly impact people's desires to use private cars, thus the lack of "reasonable" policy for car park management may pose challenges.

- The establishment of specific policies and incentives is required to mandate emission standards for private motor vehicles. Besides the policy of subsidies for new energy vehicles issued by Tianjin municipal government, SSTEC has not got a specific vehicle emission policy for promoting the use of low emission vehicles. This would be counterproductive to the introduction of new vehicle technologies. Furthermore, travel demand management (TDM) policy is still not developed in

[33] Park and Ride (P&R) park refers to car park with connections to public transport services, allowing people headed to city centers to complete their journey by bus or rail system.

the Eco-city, which adversely impacts the discouragement of the use of private automobiles and improvement of traffic flow.

- According to SSTEC's transport planning, the main freight transport mode in the Eco-city is only road transportation, the most carbon-intensive mode compared with rail and port transportation. Moreover, except the policy of subsidies for new energy vehicles issued by Tianjin municipal government, there is no specific policy for stimulating the use of low emission trucks. This will lead to the hidden trouble of air pollution, carbon emissions, noise emission and congestion for the future.

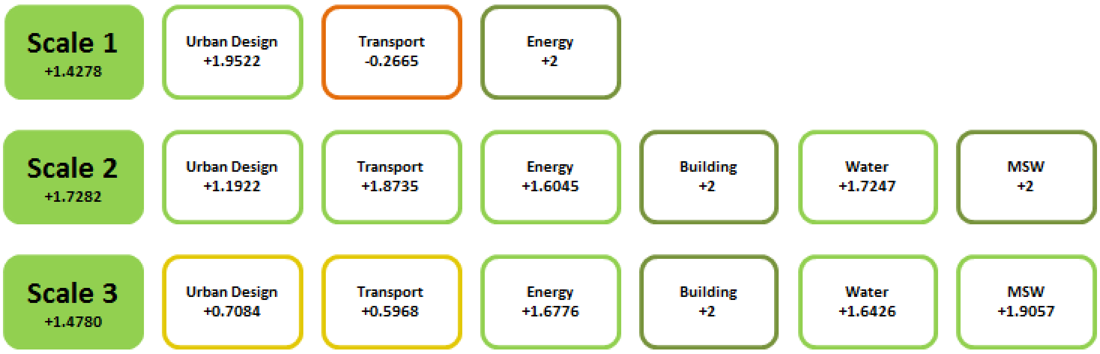

Figure 5.11 LCISS evaluation result of SSTEC

5.5.3 Development guideline of Sino-Singapore Tianjin Eco-City

This section provides development guidelines for SSTEC based on the evaluation checklist and evaluation report. Earlier chapters discussed low-carbon city development in categories of urban design, transport, energy, building, water, and municipal solid waste. Accordingly, this section describes SSETC's possible actions with the same categories.

Table 5.4 Development guideline of SSTEC

Recommendation	Planning scale	Responsible department
Urban Design		
Divide the green cells into smaller blocks: Dividing some of SSTEC's 400m by 400m blocks into small-scale blocks with side length of 150-200m will help enhance the road network density, especially the density of branch road network, in order to encourage non-motorized transport and decrease traffic congestion.	Scale 2 and 3	Construction Bureau SSTEC
Transport		
Promote intermodal freight transport: SSTEC is located adjacent to the mouth of the Yong Ding Xin River, Tianjin port, and several rail lines. Such a geographic location provides the	Scale 1	Transport Bureau SSTEC

Eco-city a great potential of intermodality development. In an intermodal situation, the CO_2 emissions from freight transport will be reduced because the rail and waterway mode are less carbon-intensive than motorized road transport. Additionally, it also contributes to alleviate road traffic and pollution problems.		
Develop transportation demand management (TDM) strategy for car access restriction: The suggested TDM strategy for SSTEC includes: (i) reduce parking supply: the availability of parking is one of the determinants influencing how people choose to travel – an oversupplied parking results in excessive car use and associated carbon emission, pollution and traffic congestion; (ii) differentiated parking pricing (i.e. parking pricing graded according to parking location, parking duration, and vehicle emission level): parking cost is another determinant impacting people's desires to use their motor vehicles – if the parking fee is too low, car owners will not take it into consideration when making travel choice ; (iii) auto restricted zones (i.e. any land area where vehicular travel is restricted in some manner). All these measures can support the modal shift to non-motorized and public transport and to avoid unnecessary trips.	Scale 3	Transport Bureau SSTEC
Develop low emission vehicles stimulation policy: Providing incentives for vehicles that limit emissions to the National Discharge Standard of Vehicle Pollutant (Ⅴ Stage) or new energy vehicles (this includes financial incentives, such as subsidies on low emission auto purchase, lower road taxes and parking fees, etc.; imposing restrictions on the use of high emission vehicles, such as no permission to enter auto restricted zones, or other forms of penalty).	Scale 3	Transport Bureau SSTEC
Enhance the quality of non-motorized transport system: Since the design standard of non-motorized transport system in SSTEC's master plan is too low that the width of footpaths and cycle tracks is not sufficient, an upgraded design standard (footpath width ≥4m; one-way cycle track width ≥4m; two-way cycle track width ≥6m) is suggested to implement. In addition, more variety should be added to the design of green belts along non-motorized system to reduce monotonous look that makes people get easily bored. Such measures should support the SSTEC's objective of encouraging walking and cycling.	Scale 3	Constructio n Bureau SSTEC
Energy		
Establish green electricity program: Green electricity program enables end users to express their preference of using	Scale 3	Economy Bureau

renewable energy. Through adequate marketing and dissemination efforts, green electricity program will be an effective supporting mean of achieving SSTEC's object of utilize 20% of its energy from renewable sources.		SSTEC
Building		
Introduce of a validated standard for green building design: SSTEC may need to apply an internationally recognized building certification system (e.g. the Deutsche Gesellschaft für Nachhaltiges Bauen – DGNB program, or the Leadership in Energy and Environmental Design – LEED program) to validate the effectivity of SSTEC's green buildings.	Scale 3	Tianjin Eco-City Green Building Institute
Water		
Improve the design standard of drainage system and flood control system: Climate change will cause sea level rise, and more frequent and intensive flood and storm surge along the coast of China. This challenge the drainage and flood control capacity in the coastal cities. As the sea level rise of SSTEC's surrounding waters is projected to be 0.5m, the designs of its drainage system and flood protection should be appropriately enhanced.	Scale 3	Water Affairs Bureau SSTEC
MSW		
Develop a comprehensive measure of waste separation: Given the SSTEC's ambitious objective of attaining 80% source separation of municipal solid waste, the development of a comprehensive measure of waste separation is suggested, including publicity and education about the knowledge of waste sorting, and implementation of differential pricing of waste management service that source-separated waste pay less fee than not separated.	Scale 3	Sanitation Bureau SSTEC

5.5.4 Evaluation results summary

In this chapter, exemplified by Sino-Singapore Tianjin Eco-City, the evaluation method of Low-Carbon Indicator System – Sino is studied. As shown in the evaluation result, SSTEC has a well-performed strategy for low-carbon city development, but there is still room for improvement in several sectors. According to local expert investigation and annual development report of SSTEC, the evaluation result matches the actual status of the eco-city. Through the LCISS evaluation, the improvements are identified, such as traffic management, building certification, flood control, waste recycling regulations, etc.

As mentioned in 5.1, the phased development schedule of SSTEC provides itself the opportunity of "doing by learning and learning by doing", which supports integrations of such improvements into its planning. At present, the first phase of construction has been completed, and the second phase of development, which is especially important for spatial form solidification, is underway. For this reason, SSTEC should summarize key lessons learned from Phase I in order to better offset its weakness and foster its strength. The application of LCISS addresses SSTEC of this need, and enables the measurements of the performance of Eco-city and quantification of its success.

It should be noted that the case study is only an example of how the LCISS could be applied for evaluation of low-carbon development levels of Chinese cities. The in-depth discussion of low-carbon development of SSTEC is neither supposed to be the final purpose of the case study given the limitation of data availability nor the focus of this work. However, it should be considered in future work.

Chapter 6 Conclusion and Future Work

6.1 Conclusion

The main objective of this work is to develop a low-carbon city evaluation system to provide standards and guidance for the development of low-carbon cities in China. For this aim, insufficiencies of the existing research results and the improving direction are analyzed, and the significance of six climate-related urban sectors “urban design”, “transport”, “energy”, “building”, “water”, and “municipal solid waste” in low-carbon city evaluation are studied in depth. On this basis, the evaluation system “Low-Carbon Indicator System – Sino (LCISS)” is constructed, and is empirically examined by a case study in Sino Singapore Tianjin Eco-City (SSTEC). The main contents and conclusions of the thesis are as follows:

Background review

The relationship between cities and climate change has been discussed in depth, which makes the fact that cities play key roles in mitigating and adapting to climate change more clear, and low-carbon city development is an inevitable choice to address climate crisis and to position for sustainable development.

This thesis conducted a major review of the research background of low-carbon cities and low-carbon city evaluation, it found that:

- In theoretical research, scholars from different disciplines and fields have studied the low-carbon city from different approaches, and have come up with fruitful achievements, but owing to the differences in theoretical foundation, discipline background, and spatial scale between these researches, the findings cannot be easily integrated and applied.

- In practical research, low-carbon city practice is still in the exploration stage that is characterized as spontaneous, unsystematic, and tentative. Most pilot projects focused on improving energy efficiency, adjusting the energy structure, promoting green traffic systems and green buildings, and advocating low-carbon life and consumption.

- In low-carbon city evaluation research, most achievements are developed in different disciplines with different evaluation objectives, functions, and applicable scopes, which lack uniform standard. In China, the main insufficiencies of the research in this field include: insufficient evaluation on climatic adaptability; unadaptable to urban planning system; lack of local characteristics for cities with different scales, natural environment, economy and social development; confusion between "evaluation indicator" and "evaluation target".

Key urban sectors of low-carbon city

Six key urban sectors of low-carbon city evaluation were identified, each of the sectors were studied from the perspective of analyzing their significance of low-carbon city development, carbon emission contribution and climate risk, and proposing the corresponding climate mitigation and adaptation strategies. The main findings include:

· *Urban Design* is the key to success in low-carbon development, since it determines urban form which has considerable and continuous impact on energy use, resource consumption, and the climate change adaptation and mitigation ability of a city. Transportation, building energy consumption and conversion of land use are the most crucial links between CO_2 emission and urban form. From another point of view, climate change impacts influence urban design through deciding the location of industry facilities, transport infrastructure, housing, green space and other investments, so as to ensure a city can adapt to climate change. In this sector, the mitigation and adaptation strategy is to optimize urban form through promoting the development of compact urban growth, mixed land use, transit oriented development (TOD), and green infrastructure.

· *Transport* is interpreted to be one of the key and growing sources of greenhouse gas emissions, accounting for 22% of energy-related carbon dioxide emissions globally. The factors that affect the amount of CO_2 emissions caused by urban transport mainly include travel demand, CO_2 emissions per passenger-km, and vehicle energy efficiency. Moreover, urban transport is very vulnerable to climate change so the transport infrastructure, vehicles, and mobility behavior will be largely influenced by the anticipated impacts of climate change, such as hotter weather, intense rains and floods, higher sea levels, and extreme weather, etc. In this sector, the mitigation and adaptation strategy is to reduce travel or the need to travel, promote climate-friendly transport modes, and improve the efficiency of motorized transport.

· *Energy* is mainly required for heating, cooling, and lighting in residential, commercial, industrial, and public spaces in a city. Globally, energy is generated mostly from fossil fuels, which contributes to global warming, meanwhile, leading to serious environmental pollution and energy crisis. Energy production and distribution efficiency, energy demand, and energy structure are the crucial factors affecting the carbon emissions from this sector. On the other hand, energy supply and demand in cities is also complicated by the anticipated climate change effects, e.g. warmer temperatures will drive energy demand upwards, and climate-related hazards will impact on primary energy fuel supply, energy production operation, and energy transmission and distribution. In this sector, the mitigation and adaptation strategy is to optimize energy structure by increasing the share of renewable energy, new energy and clean energy in the energy structure, and to control energy demand by improving energy efficiency and encouraging utilization of low carbon-intensity energy.

- *Building* is estimated to consume more than 40% of total primary energy worldwide, and contribute 30% of the world's annual GHG emissions. In a building's whole lifespan, energy consumption and carbon emissions take place in five phases of materials production, materials transportation, building construction, building operation, and demolition, from which the material production and building operation are the most energy- and carbon-intensive ones. In the meantime, as climate change intensifies, a series of anticipated impacts and hazards will seriously challenge buildings' safety, drainage capacity and other aspects. In this sector, the mitigation and adaptation strategy is to promote green building generalization, improve building energy efficiency, and push for large-scale application of renewable energy in buildings.

- *Water* is a sector that is not currently a major carbon emitter, however, it has great potential to lower emission levels. In urban areas, water and energy are inseparably linked, because energy is required in the process of water capture, transport, treatment and heating, wastewater treatment, transport and disposal. And this implies the generation of carbon emissions in the case of fossil-fuel consumption. From another point of view, impacts of climate change, such as rising sea levels, more frequent and intense rainfall as well as extended dry periods, will threaten urban water infrastructures with breakdown of service, decreased storage for potential emergencies, lowered water quality, and increased energy consumption for system operation and maintenance. In this sector, the mitigation and adaptation strategy includes water demands reduction, water reclamation and recycling, and capacity improvement of drought and flood prevention.

- *Municipal solid waste (MSW)* is a fast-growing carbon emitter, representing approximately 5% of carbon emissions in urban areas. In the lifecycle of MSW, GHG emissions are generated in the processes of waste collection and transport, recycling/composting, and disposal (incl. incineration and landfilling). On the other hand, climate change will adversely affect the future development and operation of municipal solid waste management facilities and infrastructures in various ways, such as increased risk of damage to constructions of waste management sites due to the potential intense precipitation events, increased risk of fires at open dumpsites due to warmer temperatures, increased risk of damage to facilities at low lying sites due to higher sea levels, etc. In this sector, the mitigation and adaptation strategy includes MSW prevention and MSW recycling.

Development of Low-Carbon Indicator System – Sino

As the major focus of the thesis, a new evaluation framework of low-carbon city development level – Low-Carbon Indicator System – Sino (LCISS) integrates urban planning and the aforementioned key urban sectors were proposed on the basis of the investigation above. The LCISS consists of three parts: "indicator list", "evaluation checklist and report", and "development guideline". "Indicator list" is the evaluation tool. "Evaluation checklist and report" is the evaluation result as well as a systematic review of the situation of a city's low-carbon development level. "Development guideline" is an action plan that describes where improvement is needed in the future.

Indicator list, as the main body of LCISS, is a comprehensive indicator system that is constructed through coupling three urban planning scales, i.e. macro, middle, and micro scale, and six key urban sectors of urban design, transport, energy, building, water, and MSW. The indicator list was organized as a three-level hierarchic structure that contains 6 first-class indicators, 17 second-class indicators, and 54 third-class indicators. Among them, first-class indicators involve the six key urban sectors; second-class indicators are determined in terms of the climate mitigation and adaptation strategies of each key sector; third-class indicators are selected by using the Theoretical Analysis and Delphi methods. Considering different indicators have different significance and applicability, third-class indicators were classified into essential indicator, and expanded indicator. The weight of all indicators is determined by use of both the Delphi method and Analytic Hierarchy Process (AHP) method. In LCISS, the performance of an indicator is marked with normalized scores between -2 and +2.

LCISS could help cities to evaluate the process and status of their low-carbon development, to identify where inefficiencies occur as well as where action is needed, to assess the potential for improvement, and to formulate an action plan, so as to advance the low-carbon development in a more efficient way.

Application case of Low-Carbon Indicator System – Sino

To examine the validity and operability of LCISS, it was used to evaluate the low-carbon development level for a pilot project of Sino-Singapore Tianjin Eco-City (SSTEC). The evaluation results showed that SSTEC has advantages in low-carbon development at all three urban planning scales, but there is still room for improvements in several sectors, such as traffic management, building certification, flood control, waste recycling regulations, etc. This is the same as the fact of SSTEC's development. At the present time, SSTEC's first phase construction has been completed, and the second phase of development is underway. The application of LCISS could help SSTEC to summarize key lessons learned from Phase I and better eliminate its weakness and foster its strength.

6.2 Contributions of the study

Low-carbon city focus on both climate mitigation and adaptation

Low-carbon city is the inevitable choice in the context of global climate change for urban sustainable development. However, the concept of a low-carbon city has not been unanimously agreed on because it is still its early stages of study. Unlike most of the existing research which have always put the research focus on climate mitigation, in this thesis, the "low-carbon city" is defined as a city that strives to reduce its GHG emissions and increase its carbon sinks, while simultaneously adapting to the anticipated climate change impacts. This definition suggests that climate mitigation and adaptation are two key points of low-carbon city development with the same significance, and accordingly, identifies these both as the main basis of low-carbon city evaluation. This can provide a new boundary condition of low-carbon city evaluation.

A coupled model with low-carbon city evaluation and urban planning

This thesis introduces urban planning into the study of low-carbon city, in order to link the disjunction between the low-carbon development strategy and the urban planning system in Chinese cities. Urban planning is the important basis of urban construction and management; furthermore, it has a major impact on the implementation of climate mitigation and adaptation actions. Therefore, evaluation of a low-carbon city should be integrated with the urban planning system, so as to enhance the guidance for urban planning to low-carbon city construction, and make the evaluation more scientific.

Low-carbon city evaluation with specific characteristics

As discussed in 1.3, China has a special national condition which differs from most other countries. This decides that the low-carbon city development and evaluation in China has its own background. Therefore, in order to ensure the major finding of the thesis "Low-Carbon Indicator System – Sino (LCISS)" to have rather strong practice guidance and operability, in the process of indicator selection, Theoretical Analysis method and Delphi method were used to analyze the applicability of all indicators in Chinese cities.

Furthermore, even inside China, the carbon-reduction potential and climate vulnerability vary from city to city, according to its size, natural environment, economy and social development. Accordingly, this study believes that the local characteristic of a city shall be reflected in low-carbon city evaluation. For this purpose, LCISS was designed with two types of indicators: essential indicator and expanded indicator, the former is a binding indicator of LCISS, and the latter can be applied flexibly in accordance with the indicator applicable condition and scope and the actual situation of the target city. This will enable cities to determine the evaluation content based on their characteristics to an extent. Additionally, the weight of indicators in LCISS is determined by the AHP method, Delphi method and local expertise and experiences of the target city, which could make weight factors in evaluation accord well with the fact. These approaches provide a new way of thinking way for factoring cities' local characteristic into low-carbon city evaluation.

Diagnostic low-carbon city evaluation

In the thesis, one of the most important features of the evaluation framework LCISS is that it is a diagnostic evaluation, which can identify a city's problem in different sectors and on different urban planning scales. In LCISS, "evaluation checklist" and "evaluation report" summarize a city's status of low-carbon city development and help the city to understand the current achievements, to define the gap between the reality and the low-carbon development objective, to identify its strengths and weaknesses; "development guideline" provides recommendation for future improvement. Compared to most of the existing achievements of "evaluation target" in China, diagnostic evaluation could orient cities' low-carbon development in a more efficient way.

6.3 Future work

In China, the low-carbon city evaluation is still a new lesson. Although this thesis made some progress in this research field, because of the limited resources and time, there is still room for further research. To enhance the recognition of LCISS by the Chinese authorities, additional efforts are needed in the following areas.

- Select more cities as case studies, so as to further test the validity and operability of LCISS. In consideration of scientific principles, although LCISS was exemplified by the case of SSTEC and its evaluation result is consistent with the current development status, this evaluation system still needs to be further examined by other cases.

- If data is available, more disaggregated evaluation indicators within the key urban sectors can also be developed, in order to provide a basis for more accurate and specific evaluation. For example, for the municipal solid waste sector, "waste recycling rate" and "separate waste collection rate" could be used. For the water sector, "stormwater collection and reuse rate" could also be used.

- Disseminate the findings of the thesis through scientific journals, conference presentations and academic interviews, in order to enrich the theory of low-carbon city evaluation, and to provide practical guidance for low-carbon city construction in China.

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Appendix 1

Objectives of low-carbon urban development strategy in China (2009-2020)

Sector	Sub-target	No.	Indicator	Unit
Economy	Optimize the industry structure, and enhance economic performance	1	Per capita GDP	ten thousand yuan
		2	GDP growth rate	%
		3	Share of tertiary industry in GDP	%
		4	Employment rate of tertiary industry	%
	Recycle resources, and improve energy efficiency	5	Energy consumption per unit of GDP	ton of standard coal
		6	Elasticity of Energy Consumption	
		7	Carbon emission per unit of GDP	ton of standard coal
		8	Usage of Renewable Energy	%
		9	Proportion of electricity generated by multi-generation	%
	Increase input on Research & Development investment, and promote technology innovation	10	Proportion of financial expenditure on R&D investment	%
Society	Cater to the housing needs of low income group	11	Proportion of residential land area for low-rent house	%
		12	Per capita living space	m^2
		13	Proportion of net income of land transfer on low-rent house construction	%
	Improve the quality of life for residents	14	Per capita disposable income	ten thousand yuan
		15	Engel coefficient	%
		16	Urbanization rate	%
	Develop bus rapid transit system, and encourage residents to travel "green"	17	Average walking distance to BRT stations	m
		18	Bus ownership per 10000 people	
Environment	Improve city's carbon sequestration capacity	19	Forest coverage	%
		20	Per capita green area	m^2
		21	Greenery coverage rate of urban built-up area	%
	Reduce pollution emission, and upgrade urban environment	22	Domestic waste harmless treatment rate	%
		23	Treatment rate of wastewater	%
		24	Discharge standard-meeting rate of industrial wastewaters	%
	Mitigate climate change through low-carbon design	25	Proportion of low energy consumption building	%
		26	Proportion of carbon capture and store (CCS)	%

Appendix 2

Low-carbon economy (city) comprehensive evaluation index system

First-class indicator	No.	Second-class indicator	Unit
Low-Carbon Production Indicator	1	Carbon net productivity	RMB10000/ton carbon equivalent (tce)
	2	Energy consumption of unit product of key industry	tCO_2
Low-Carbon Consumption Indicator	3	Carbon emission per capita	tCO_2/per capita
	4	Domestic carbon emission per capita	tCO_2/per capita
Low-Carbon Resource Indicator	5	Share of non-fossil fuels in primary energy consumption	%
	6	Forest coverage	%
	7	Carbon emission per unit energy consumption	tCO_2/tce
Low-Carbon Policy Indicator	8	Development planning of low-carbon economy	-
	9	Establishment of carbon emission surveillance system, with statistic and monitoring function	-
	10	Popularity rate of knowledge of low-carbon economy	%
	11	Implementation rate of building energy-saving standard	%
	12	Incentive measures of non-commercial energy	-

Appendix 3

China low-carbon city evaluation index/indicator system

Main Indicator		
Primary indicator	**No.**	**Secondary indicator**
Economy	1	Carbon productivity
	2	Energy intensity
	3	Decoupling index
Energy	4	Percentage of non-fossil energy in primary energy consumption
	5	Per capita non-commercial renewable energy use
	6	Carbon intensity of energy
Infrastructure	7	Energy consumption per unit building area for public buildings
	8	Energy consumption per building are for residential buildings
	9	Ratio of green transport
Environment	10	Percentage of days with API less than 100
	11	Domestic water consumption per capita per day
	12	Forest coverage rate
Society	13	Urban-rural income ratio
	14	Per capita CO_2 emission
	15	Low-carbon management institution

Supporting Indicator		
Major area	**Primary indicator**	**Secondary indicator**
Urban management	1.1 Planning	1.1.1 GHGs emission inventory
		1.1.2 Low-carbon development strategy
		1.1.3 Measurability and presentation of low-carbon concept in urban planning
		1.1.4 Proportion of local governmental budget on low-carbon development special funds (incl. energy-saving, renewable energy, environmental protection, etc.)
	1.2 Implementation of low-carbon planning and policies	1.2.1 Incentive measures of promotion of low-carbon and green economic development
		1.2.2 Demonstration projects of low-carbon community/school/mall/supermarket
		1.2.3 Green purchasing
		1.2.4 Openness/Availability of information of low-carbon planning and management
	1.3 Low-carbon management for utilities	1.3.1 Energy consumption of centralized heating
		1.3.2 Gas supply coverage
		1.3.3 Usage of renewable energy
		1.3.4 Energy consumption per unit water supply
		1.3.5 Energy consumption per m^3 wastewater treatment
		1.3.6 Water-saving measures
		1.3.7 Municipal waste harmless treatment rate
		1.3.8 Measures of separate waste collection and waste reduction
Municipal economy	2.1 Low-carbon industries	2.1.1 Emissions of all other non-CO_2 in industrial processes and mitigation measures
		2.1.2 Execution of access policy of high energy consumption and high-pollution industry
		2.1.3 Elimination of backward production capacity
		2.1.4 Energy-saving standard-meeting rate of large-scale industry enterprises
		2.1.5 Proportion of key energy using units applying Energy Management System

		2.1.6 Proportion of key energy using units that have signed up to voluntary climate pact
		2.1.7 Share of renewable energy/energy-saving product value in total industrial production
		2.1.8 Utilization of renewable energy in industrial processes
		2.1.9 Comprehensive utilization rate of industrial solid waste
	2.2 Low-carbon services	2.2.1 Proportion of well-trained energy managers in hospitals/schools/malls/hotels/airports
		2.2.2 Proportion of service enterprises that have signed up to voluntary climate pact
		2.2.3 Amount of enterprises providing energy service, energy performance contracting, CDM service, and energy advisory service
	2.3 Low-carbon agriculture	2.3.1 Usage of chemical fertilizers per unit acreage
		2.3.2 Proportion of households with firedamp pool
		2.3.3 Treatment and reuse of farming and forestry surplus
		2.3.4 Energy-saving measures in agricultural production process
Green building	3.1 Planning	3.1.1 Application of energy consumption statistical tools in different building types
		3.1.2 Development of green building action plan
		3.1.3 Planning of energy consumed in buildings in new urban area
	3.2 Green building management	3.2.1 Implementation of building energy/low-carbon management
		3.2.2 Existing buildings energy-saving transformation
		3.2.3 Application of renewable energy in buildings
		3.2.4 Green building related capacity building activities
		3.2.5 Promotion of green building
		3.2.6 Implementation of green building related incentive policies and measures
		3.2.7 Demonstration project of low-carbon technology application
Low-carbon transportation	4.1 Low-carbon transport strategy and planning	4.1.1 Establishment of energy consumption and carbon emission lists for different traffic modes
		4.1.2 Low-carbon transportation strategy and action plan
	4.2 Transport management	4.2.1 Transportation integration management
		4.2.2 Average commuting time
		4.2.3 Share of new energy vehicles in public service vehicles
		4.2.4 Application of energy-saving lamp/lamp using renewable energy in roadway lighting
		4.2.5 Service level of public transport
		4.2.6 Number of low-carbon awareness promotion activities per year
		4.2.7 Number of people attending low-carbon training programme and capacity building activities per year
		4.2.8 Planning and maintenance of infrastructure of non-motorized transportation

Appendix 4

Evaluation index on green and construction for key small cities & towns (trial)

Type (and weightings %)	Evaluation of projects	Proportion (%)
Social and economic development level (10)	1. Ability of public finances	2
	2. Energy consumption	2
	3. Ability of absorbing employment	2
	4. Social security	2
	5. Characteristics of industry	2
Planning and construction management level (20)	6. Planning sophistication	5
	7. Management agencies and performance	2
	8. Building management system	2
	9. Higher level of government support	4
	10. Town appearance	7
Construction land intensive level (10)	11. Built-up area of construction land area per capita	2
	12. Industrial park land use intensity (Note: This does not score without industrial park)	3
	13. Administrative office facilities conserve degrees	4
	14. Suitability for road use	1
Resources, environmental protection and energy saving level (26)	15. Township air pollution index (API index)	1
	16. Quality of town surface water	1
	17. Township average of ambient noise	1
	18. Industrial and mining pollution	2
	19. Energy-efficient buildings	4
	20. Use of renewable energy	3
	21. Water saving and water reclamation	3
	22. Sewage treatment and disposal	6
	23. Garbage collection and disposal	5
Infrastructure and landscaping level (18)	24. Built-up area road traffic	6
	25. Water supply system	3
	26. Drainage system	4
	27. Landscaping	5
Public services level (9)	28. Built-up area housing situation	1
	29. Educational facilities	2
	30. Medical facilities	2
	31. Commercial (bazaars) facilities	2
	32. Public sports and entertainment facilities	1
	33. Public toilets	1
Historical and culture protection and characteristics construction	34. Historical and cultural heritage protection	3
	35. Towns features	4

Appendix 5

Beijing ecological demonstration area evaluation standard

Type	No.	Item	Score
Land use layout	1	Transit oriented development (TOD) mode	3
	2	Employment housing equilibrium	4
	3	Mixed land use	4
	4	Exploitation and utilization of underground space	3
	5	Small-scale building block /community	3
	6	Coverage of public transport station	5
	7	Public transport services and facilities	4
Ecological environment	8	Proportion of woodlot in green space	2
	9	Reasonable green space planning	6
	10	Proportion of sunken lawn	3
	11	Net loss of natural wetlands	4
	12	Control of heat island effect	4
	13	Separate waste collection and waste recycling	3
Green transportation	14	Non-motorized transportation	6
	15	Green transportation rate	6
	16	Bicycle sharing system	4
	17	Transfer distance	3
	18	Green road design	4
	19	Barrier-free facilities	2
Energy utilization	20	Diversifying sources of energy supply	2
	21	Energy consumption of new building	5
	22	Establishment of energy monitor system	2
	23	Energy utilization type	3
	24	Coverage of recharging devices for new energy vehicles	2
	25	Potential for future renewable energy production	1
	26	Utilization of renewable energy	5
	27	Unified energy management and operation	2
	28	Establishment of energy management agency	2
Water utilization	29	Quality of water environment	2
	30	Flood protection and drainage facilities	2
	31	Stormwater management system	2
	32	Irrigation	1
	33	Rain and wastewater diversion and treatment rate of wastewater	2
	34	Low impact development	4
	35	Reclaimed water supply system	4
	36	Water supply from non-traditional sources	5
Green building	37	Proportion of green building	10

	38	Share of green building in large public buildings	5
	39	Transformation rate of existing buildings	5
	40	Finished house rate	4
Informatization	41	Transportation management information system	4
	42	Planning for various information system	3
	43	Comprehensive digital city management system	2
	44	Coverage of wireless network	3
	45	Establishment of information service system for citizens	2
Innovation	46	Redevelopment of unused land and abandoned land	2
	47	Reconstruction of historical blocks	2
	48	Local characteristics of Beijing	3
	49	Statistic of carbon emissions	2
	50	Biodiversity	4
	51	Utilization of microgrid technology	2
	52	Low-carbon life style	2
	53	Public participation	2
	54	Innovation of management mechanism	4

Appendix 6

KPI framework of the Sino-Singapore Tianjin Eco-City

Quantitative Indicators						
	KPI area	No.	KPI details	Units	Indicative value	Timeframe
Healthy Ecological Environment	Good natural environment	1	Ambient air quality	Days	No. of days per year in which ambient air quality meets or exceeds China's National Ambient Air Quality Grade Ⅱ Standard ≥310 (i.e. 85% of 365 days)	Immediate
				Days	No. of days per year in which SO2 and NOx content in the ambient air should not exceed the limits stipulated for China National Ambient Air Quality Grade Ⅰ standard ≥155 (i.e. 50% of 310 days)	Immediate
					To meet the standard stated in the PRC's National Standard GB 3095-1996	By 2013
		2	Quality of water bodies within the Eco-city		To meet Grade Ⅳ surface water quality standard stated in the latest PRC's National Standard GB 3838-2002	By 2020
		3	Water from taps attaining drinking water (potable) standards	%	100	Immediate
		4	Noise pollution levels must satisfy the stipulated standards for different functional zones	%	100	Immediate
		5	Carbon emission per unit GDP	tons per 1 million US dollars	150	Immediate
		6	Net loss of natural wetlands		0	Immediate
	Balance of man-made environment	7	Proportion of green buildings	%	100	Immediate
		8	Local/ Native plants index		≥ 0.7	Immediate
		9	Public green space per capita	m^2 per capita	≥12	By 2013

Social Harmony & Progress	Social harmony & progress	10	Per capita domestic water consumption	litres per day per capita	≤120	By 2013
		11	Per capita domestic waste generation	kg per day per capita	≤0.8	By 2013
		12	Proportion of green trips	%	≥30	Before 2013
					≥90	By 2020
	Comprehensive infrastructure	13	Overall recycling rate	%	≥60	By 2013
		14	Provision of free recreational and sports facilities within walking distance of 500m	%	100	By 2013
		15	Treatment to render solid waste non-hazardous	%	100	Immediate
		16	Barrier-Free Accessibility	%	100	Immediate
		17	Service network coverage	%	100	By 2013
	Sound management mechanism	18	Proportion of public housing	%	≥20	By 2013
Dynamic and Efficient Economy	Sustainable economic development	19	Renewable energy usage	%	≥20	By 2020
		20	Water supply from non-traditional sources	%	≥50	Bt 2020
	Vibrant technological innovation	21	Number of R&D scientists and engineers per 10,000 labour force	man-years	≥50	By 2020
	Overall balanced employment	22	Employment-Housing Equilibrium Index	%	≥50	By 2013

Qualitative Indicators				
	KPI area	NO.	KPI	KPI description
ed Region al C...	Coordinated natural ecology	1	Healthy ecological safety, advocating green consumption, low carbon operations	To maintain an integrated regional ecology, strengthen ecological safety and establish a sound regional ecological security system within the Eco-city, from the perspective of the optimum usage of regional resources and energy, and the capacity of the environment.

	Coordinated regional policies	2	Advance innovative policies, united anti-pollution policies in place	Actively participate in and promote regional cooperation, and implement the principle of uniformity of public services. Regional policies should ensure regional policy coherence. Establish a sound regional policy system to ensure the improvement of the surrounding areas.
	Social and cultural coordination	3	(Give) prominence to the river estuarine cultural character	Urban planning and architectural designs should preserve history and cultural heritage; manifest the uniqueness, while protecting ethnic, cultural and scenic resources. Also, to ensure safe production and social order.
	Regional coordinated economy	4	Supplementing the recycling economy Supplementing the recycling economy	Sound market mechanism to overcome the limitations of administrative divisions, drive the orderly development of the surrounding region, promote a reasonable division of functions at the regional level, as well as a orderly market, and relatively balanced economic development and living standards.

Appendix 7

Ecological indicator system of Tangshan Bay Eco-City

System 1: Urban Function				
Aspect	No.	Indicator	Value	Unit
Residence	1	Urban population density	13000	Dweller/km^2
	2	Residential area per capita	28.1	m^2 per capita
	3	Proportion of low-rent housing	>20	%
	4	Mixture of multiple forms of housing property right	>20	%
	5	Mixture of residence of different size and price	>20	%
Accessibility of public spaces and facilities	6	Provision of basic service functions within distance of 400m	100	%
	7	Public building area per capita	0.5	m^2/person
	8	Cultural building area per capita	0.5	m^2/person
	9	Proportion of financial budget on green space investment	——	%
	10	Proportion of financial budget on public building investment	——	%
	11	Land used for higher education and research per capita	20	m^2/person
Diversification and functional mix of workplace	12	Average density of workplace within CBD	>20	%
	13	Functional mix: housing/office/service/workplace in different blocks/communities	H: 50-80 WS: 20-50	%
	14	Proportion of middle and small office in office building	20	%
Residence in high risk area	15	Proportion of residential building in high risk areas (e.g. volcano)	0	%
	16	Proportion of residential building in industrial pollution areas	0	%
	17	Proportion of residential building in sea flooding high risk areas	0	%
Diversification and functional mix of work areas	18	Functional mix: proportion of commercial/public facilities/work areas in different districts	H: 50-80 WS: 20-50	%
	19	Proportion of SOHO housing (small office in residential area)	3-5	%
	20	Share of residential building in functional mix area (at nodes)	H: 40-50 WS: 50-60	%
Universality, flexibility, and stability of urban structure	21	Changes in urban density	0.5-2.5	Net. U. D=GFA/NGA
	22	Proportion of small-scale block	50	%
	23	Pattern of integrated road and street	——	——
Friendly	24	Net of footpaths and cycle tracks	——	——

environment for pedestrians and cyclists	25	Space combination: integration of local road network for pedestrians and cyclists	——	——
Quality of urban environment	26	Neutral of simplicity and complexity	——	——
	27	Neutral of openness and closure	——	——
	28	Legibility of position and guide sign	——	——
	29	Legibility of local road network structure	——	——
	30	Recognition of afforestation	——	——
	31	Recognition of water space	——	——
	32	Maintenance and order	——	——
	33	Historical style	——	——
	34	Creative architecture	——	——

System 2: Building and Construction Industry				
Type	No.	Indicator	Value	Unit
Architectural design	35	Urban, building, and interior design from architectural and aesthetical perspective	——	——
	36	Spirit of place and local cultural line	——	——
	37	Demonstrative design, general applicability and flexibility	——	——
Chemical composition	38	Establishment of database of building construction	——	——
	39	Development of harmful substance list	——	——
Interior environment	40	Sound environment	<35	db
	41	Air quality: radon concentration	<50	Bq/m3
	42	Air quality: ventilation	100	%
	43	Air quality: nitride concentration	<70	Bq/m3
	44	Summer interior temperature	27	℃
	45	Winter interior temperature	20	℃
	46	Interior natural illumination	——	——
	47	Humidity control	0	%
	48	Water temperature (no legionella-contamination)	70	℃
Eco-cycle system	49	Practice eco-cycle system based on subsystem indicators of energy, water and waste	——	——
	50	Practice eco-cycle system based on the concept of sustainable development	——	——
Building and structure	51	Application of validated standard and environmental management system	ISO 9000 + ISO 14000	
	52	Application of rating system consistent with the actual situation of China (e.g. Swedish building environment rating system, LEED, etc.)	ECB：A level LEED: Platinum	
Sustainable building	53	Share of environmental-friendly building, A level	90	%
	54	Share of green building of residential building, A level	100	%
	55	Share of green building of industrial building, A level	100	%
	56	Share of green building of office building, A level	100	%
	57	Share of green building of public building (e.g. school), A level	100	%

System 3: Traffic and Transportation				
Aspect	No.	Indicator	Value	Unit

accessibility	58	Proportion of large-scale work area accessing to public transport system within a walking distance of 600-800m	100	%
	59	Coverage of park-and-ride station	100	%
	60	Proportion of residential area accessing to public transport system within distance of 500m	90	%
	61	Proportion of residential area accessing to public transport system within distance of 800m	90	%
	62	Proportion of work area accessing to public transport system within distance of 500m	90	%
	63	Proportion of work area accessing to public transport system within distance of 800m	90	%
	64	Proportion of areas with less than 1.5 times difference in commuting time (public transport/auto) between main home and work areas	100	%
		Proportion of areas with less than 1.5 times difference in commuting time (bicycle/auto) between main home and work areas	90	%
Efficiency and environment of transportation system	65	Proportion of motorized mode trip in long-distance trip	< 30	%
	66	Proportion of motorized mode trip in short-distance trip	< 10	%
	67	Proportion of non-motorized mode trip in short-distance trip	> 20	%
	68	Proportion of public transit trip in short-distance trip	> 70	%
Safety and environmental health	69	Rate of overspeed vehicles	0	%
	70	Proportion of vehicles exhaust in levels exceeding standards	0	%
	71	CO_2 emissions from the sector of transportation	20	tCO_2-eq/person ·km
	72	Utilization of renewable energy in the sector of transportation	75	%

System 4: Energy				
Aspect	No.	Indicator	Value	Unit
Energy demand	73	Total energy consumption (incl. transportation)	10000	kWh/person·year
	74	Electricity consumption (incl. transportation)	3500	kWh/person·year
	75	Electricity consumption of commercial buildings	50	kWh/m^2·year
	76	Energy consumption for heating of commercial buildings	15	
	77	Energy consumption for air-conditioning of commercial buildings	20	
	78	Electricity consumption of residential buildings	25	
	79	Energy consumption for heating of residential buildings (incl. water supply)	45	
	80	Energy consumption for air-conditioning of residential buildings	0	
Energy supply	81	Energy self-sufficiency rate	80	%
	82	Local renewable energy production / Local energy consumption	85	%
	83	Proportion of waste energy sourced renewable energy (excl. transportation)	95	%

System 5: Waste (Municipal Domestic Waste)

Aspect	No.	Indicator	Value	Unit
Waste generation, collection, and disposal	84	Waste output per year per capita in 2007 (incl. house and office)	438	kg/year·person
	85	Waste output per year per capita in 2020 (incl. house and office)	328	kg/year·person
		Recycled solid waste output per year per capita (incl. dweller and office worker)	3	m^3/year·person
	86	Reusable waste output per year per capita (incl. house and office)	150	kg/year·person
			2	m^3/ year·person
	87	Collection rate of hazardous and domestic waste	100	%
	88	Recycling rate (material reclamation and ecological treatment)	>60	%
	89	Percentage of landfilling	<10	%
	90	Percentage of combustion	>50	%
	91	Proportion of biological treated food waste	>80	%
	92	Waste collection frequency	every day	time/year
Convenience of Waste dumping	93	Provision of waste collection points within 50m	100	%
	94	Average distance from residential building to hazardous and large-volume waste	500	m
Accessibility of waste transfer from waste collection point	95	Provision of park places for waste transfer vehicles nearby waste collection points at a distance of 10-15m	80	%
	96	Max distance between waste collection point and waste station, when non-motorized or light vehicles applied	500	m
Resource efficiency	97	Recycling rate of NPK obtained by biochemical treatment	100	%
	98	Energy consumption of waste collection, transfer, and disposal per capita	<500	kWh/person·year
	99	Energy generation from waste treatment (combustion, methane, LFG landfill gas)	>500	kWh/person·year

System 6: Water				
Aspect	No.	Indicator	Value	Unit
Water supply and demand	100	Water consumption per capita per day	100-120	L/person·day
	101	Sources of water supply: surface river water	> 70	%
	102	Sources of water supply: underground water	0	%
	103	Sources of water supply: recycled wastewater	< 10	%
	104	Sources of water supply: collected rainwater	10	%
	105	Sources of water supply: desalted sea water	< 10	%
	106	Tap water attaining drinking water standard	100	%
Sanitation and waste generated by wastewater	107	Coverage of sanitation facility	100	%
	108	Ownership of water flushing toilets	0	%
	109	Ownership of separate treatment system of black water and grey water	90~95	%
	110	Ownership of dry sanitation facilities: bio-toilet + grey water treatment	5~10	%
Water environment	111	Water Quality: quality of river water, canal water, lagoon water, sea water, rainwater		
	112	Quality of underground water (salinity)		

	113	Salinity of marshland		
	114	Storage rate of rainwater	90	%
	115	Proportion of marshland (1m deep water)	1	%
	116	Net loss of natural wetland (incl. restored wetland)	0	%
Sea levee	117	Littoral drift (erosion/deposition) rate of east side sea levee of project	< 10	%
	118	Littoral drift (erosion/deposition) rate of west side sea levee of project	< 10	%
	119	Erosion/deposition rate of lagoon	< 10	%
	120	Erosion/deposition rate of dam	< 10	%
	121	Proportion of deposition area in the total lagoon area	< 10	%
	122	Submerged area when the MHHW is reached, if the sea levee is not taken into account	0	
Resource efficiency	123	Energy consumption of water treatment – common form of treatment	<1	kWh/m^3
	124	Desalination of sea water	<5	
	125	Energy consumption of water treatment	< 1	
	126	Proportion of recycled waste water (agricultural purpose)	> 90	%
	127	Proportion of recycled waste water (domestic purpose)	< 10	%
	128	Recycling rate of NPK obtained from biological treatment of organic waste and black water	100	%
	129	Share of black water using for methane and energy generation	100	%

System 7: Landscape and Public Space

Aspect	No.	Indicator	Value	Unit
Natural environment and city quality	130	Green coverage rate (incl. water space)	35	%
	131	Public green areas per capita	20	m^2/person
	132	Proportion of woodlot in green space	25	%
	133	Proportion of wetland/natural ecological environment in green space	20	%
	134	Proportion of financial expenditure on investment of water quality restoration of upper reaches	0.1	%
Accessibility of park and public space	135	Provision of public spaces within distance of 500m	100	%
	136	Provision of parks and public spaces (noise-level < 45dB) within distance of 3000m	100	%
	137	Provision of small-scale green spaces within distance of 50m	100	%
	138	Provision of neighbourhood public space (1-5 hectare) within distance of 200m	100	%
	139	Provision of district public space (1-5 hectare) within distance of 500m	100	%
	140	Provision of urban public space (>10 hectare) within distance of 1000m	100	%
	141	Provision of shoreline/coastline within distance of 1000m	100	%

Appendix 8

Low-Carbon Index (LCI®)

Phase 1								
S1 Urban Design								
				-2	-1	0	+1	+2
S1.1 Site planning	50%	S1.1.1 Inner city development	40%	Development on agricultural land outside the city	New development of free open space near a sub center (max. 4 km away)	New development of free open space near the city center (max. 3 km away) or near a sub center (max. 2 km away)	Brownfield development near the city center (max. 3 km away) or near a sub center (max. 2 km away)	Brownfield development near the city center (max. 2km away)
		S1.1.2 Integration to the surrounding	30%	Surrounding not covered with buildings	It is planned to cover the surrounding	Surrounding partially (<50%) covered with buildings	Surrounding is covered with buildings (min.50%)	Surrounding is nearly full covered with buildings
		S1.1.3 Regional Traffic connection	30%	No regional traffic connection	Partial regional traffic connection	Area wide regional traffic connection by 1 traffic carrier	Area wide regional traffic connection by public transport and individual traffic	Area wide regional traffic connection by individual traffic and different public transport
S1.2 Land use	50%	S1.2.1 Mixture of functions	50%	Monofunctional	2 functions, main function covers min. 80% of the area	Mixed use exist in some parts	Mixed use is dominant function	Mixed use is the dominant function, area has a center
		S1.2.2 Supplement of existing functions in the surrounding	50%	Conflict with uses in the surrounding	New uses do not fit to the uses in the surrounding	Uses are congruent to the uses in the surrounding	Uses are congruent to the surrounding and enrich them in some parts	New uses enrich the surrounding
M1 Mobility								
				-2	-1	0	+1	+2

M1.1 Motorized individual traffic	75%	M1.1.1 Position in highway network	50.0%	Long distance to the next highway	Next highway < 5km away from the border	Next highway < 2km away from the border	Next highway < 1km away from the border	Highway inside of the area, or along of a border
		M1.1.2 City-accessibility-concept	50.0%	No accessibility regulation	City-accessibility-concept for high polluting vehicles or only in several time periods of a day implemented	City-accessibility-concept for high polluting vehicles implemented	City-accessibility-concept implemented for all vehicles	City-accessibility-concept implemented, graded according to CO_2 emission
M1.2 Public transport	25%	M1.2.1 Connection to fast mass transport	50.0%	More than 2 km away from the centre	Between 1.5 and 2 km from the centre	Between 1 and 1.5 km from the centre	Between 0.5 and 1km from the centre	In the centre of the area
		M1.2.2 Quality of the mass transport connection point	50.0%	No mass transport connection	Bus	Metro or BRT	Local train + metro or BRT	Long-distance train + local train + metro or BRT

Phase 2								
S2 Urban Design								
				-2	**-1**	**0**	**+1**	**+2**
S2.1 Site planning	5%	S2.1.1 Inner city development	10%	Development on agricultural land outside the city	New development of free open space near a sub center (max. 4 km away)	New development of free open space near the city center (max. 3 km away) or near a sub center (max. 2 km away)	Brownfield development near the city center (max. 3 km away) or near a sub center (max. 2 km away)	Brownfield development near the city center (max. 2km away)
		S2.1.2 Integration to the surrounding	45%	Surrounding not covered with buildings	It is planned to cover the surrounding	Surrounding partially (<50%) covered with buildings	Surrounding is covered with buildings (min.50%)	Surrounding is nearly full covered with buildings
		S2.1.3 Regional traffic connection	45%	No regional traffic connection	Partial regional traffic connection	Area wide regional traffic connection by 1 traffic carrier	Area wide regional traffic connection by public transport and individual traffic	Area wide regional traffic connection by individual traffic and different public transport
S2.2	60%	S2.2.1 Mixture of	20%	Monofunctional	2 functions, main	2 functions, main	Mixed use exist in	Mixed use is

Land use		functions			function covers min. 80% of the area	function covers min. 50% of the areas	some part (near the housing areas)	dominant function in the central part of the area
		S2.2.2 Supplement of existing functions in the surrounding	15%	Conflict with uses in the surrounding	New uses do not fit to the uses in the surrounding	Uses are congruent to the uses in the surrounding	Uses are congruent to the surrounding and enrich them in some parts	New uses enrich the surrounding
		S2.2.3 Maintenance	15%	Large maintenance problems caused by the proposed / existing use	Smaller maintenance problems caused by the proposed / existing use	Basic needs are fulfilled near/within the residential areas	Basic needs are fulfilled close to the residential areas; additional facilities are available nearby	Basic needs are fulfilled in the study area, even for the surrounding area; additional attractions
		S2.2.4 Arrangement of uses	20%	Random allocation of the uses	Central areas have a mixture of functions	Public facilities are located central in the area	Facilities with a lot of occasional customers are located at stops of the public transport	Location of uses is chosen that they complement one another
		S2.2.5 Density allocation population/working opportunities	20%	Population density or density of working opportunities is significantly lower (<90%) than the average density of the city	Population density or density of working opportunities is lower than the average density of the city	Population density or density of working opportunities is similar like the average density of the city	Population density or density of working opportunities is higher than the average density of the city	Population density or density of working opportunities is significantly higher (>110%) than the average density of the city
		S2.2.6 Density allocation building height	10%	Density is significantly lower (<90%) than the average of the city	Density is lower than the average of the city	Density is similar like the average of the city	Density is higher than the average of the city	Density is significantly higher (>110%) than the average of the city
S2.3 Accessibility	20%	S2.3.1 Net of footpaths	30%	Area is not complete equipped with foot paths along the streets	Area is nearly complete equipped with foot paths along the streets	Area has footpaths separated from the roads	Short & direct connections to major facilities	Links to the surrounding, hierachy of paths
		S2.3.2 Net of cycle tracks	30%	Area is not complete equipped with cycle tracks	Area is nearly complete equipped with cycle tracks along the roads	Area has cycle tracks separated from the roads	Short & direct connections to major facilities by cycle tracks	links to the surrounding, hierachy of tracks

		S2.3.3 Uses at intersections	20%	Mainly undeveloped areas	No public uses	Few public uses	Private and public uses	Specific attractors
		S2.3.4 Density at important intersections (building height)	20%	Very low density	Comparatively low density	Average density of the area	Density slightly above average	Highest density of the area at the nodes and transport hubs
S2.4 Public Space	15%	S3.4.1 Existence of Public green open space	50%	No public green open space	Narrow green spaces besides the roads	Green open spaces inside the blocks	Min. 1 large green open space (min. 1 ha)	Many green open spaces
		S3.4.2 Location of green open spaces	10%	No green open spaces	Green open spaces only in the outer parts of the area	Green open spaces in the backyards	Green open spaces in the center	Many green open spaces allocated over the area
		S3.4.3 Existence of water surfaces	40%	No water surface	Small water surfaces, above ground rain water drainage	One large water surface (river/lake)	More than one water surface	Many big water surface distributed over the entire area
M2 Mobility								
				-2	**-1**	**0**	**+1**	**+2**
M2.1 Motorized individual traffic	50%	M2.1.1 Position in highway network	25.0%	Long distance to the next highway access	Next highway access < 5km away from the border	Next highway access < 2km away from the border	Next highway access < 1km away from the border	Highway access along of a border
		M2.1.2 Local roads for adjacent owners and visitors, restriction for transit traffic	25.0%	< 25% of the area	25 - 50% of the area	50 - 75% of the area	75 - 100% of the area	100% of the area
		M2.1.3 Congestion of interior road network	15.0%	Long-lasting daily overload	Daily overloads during of peak hours, < 3 hours	Short-term overloads, < 1 hour	Almost no overloads, < 0.5 hour, stronger overloads at special events only	Almost no overloads, < 0.5 hour

		M2.1.4 Car-park routing system: 1. complete registration of parking capacity; 2. Information panels inside the area; 3. Information panels outside the area; 4. Information transmission to the navigation systems	10.0%	No one criterion fulfilled	1 criterion fulfilled	2 criteria fulfilled	3 criteria fulfilled	All criteria fulfilled
		M2.1.5 Density of the road grid	25.0%	Distance between streets > 800m	Distance between streets < 800m	Distance between streets < 600m	Distance between streets < 400m	Distance between streets < 200m
M2.2 Public transport	30%	M2.2.1 Direct connection to main origin and destination areas with PT	40.0%	No connection, or only bus direct connection to some of the main origin and destination areas	Bus direct connection to the most of main origin and destination areas	Bus direct connection to all main origin and destination areas	Metro direct connection to the most of main origin and destination areas remaining connections by bus	Metro direct connection to all main origin and destination areas
		M2.2.2 Congestion frequency fast PT - metro, tram and BRT with own track (to/from main origin and destination areas)	20.0%	Long-lasting dialy congestions congestion (no arrangement)	Daily congestions during of peak hours	The most peaks can be managed (possible arrangement: special trains and stops)	Congestion only at several special events(possible arrangement: special trains and stops)	All peaks can be managed (possible arrangement: special trains and stops)
		M2.2.3 Stopping points, degree of coverage (bus, tram R = 300m; metro, BRT R=500m)	40.0%	Less than 40% of the area is covered	Between 55 and 40% of the area is covered	Between 70 and 55% of the area is covered	Between 85 and 70% of the area is covered	More than 85% of the area is covered
M2.3 Goods traffic	20%	M2.3.1 Congestion of interior road network (different peak hours as MIV)	50.0%	Long-lasting daily overload	Daily overloads during of peak hours	Short-term overloads	Overloads at special events only	No overloads

		M2.3.2 Delivery concept	50.0%	No delivery concept	Few delivery zones	Several delivery zones	Adequate number of delivery zones	Adequate number of delivery zones, custom good distribution concept for the whole area
B2 Buildings								
				-2	**-1**	**0**	**+1**	**+2**
B2.1 Building environment	40%	B2.1.1 Solar orientation	65%	< 25 % of building (blocks) are south-oriented	25 % of building (blocks) are south-oriented	50 % of building (blocks) are south-oriented	75 % of building (blocks) are south-oriented	All building (blocks) are south-oriented
		B2.1.2 Wind exposition	20%	< 25 % of buildings have a wind-exposed location	< 25 % of buildings have a wind-exposed location	Buildings are located on a plain site	< 25 % of buildings have a wind-protected location	> 25 % of buildings have a wind-protected location
		B2.1.3 Location adjacent green/ water space	15%	No buildings are adjacent green/water space	5% of buildings are adjacent green/water space	10% of buildings are adjacent green/water space	15% of buildings are adjacent green/water space	>15% of buildings are adjacent green/water space
B2.2 Building type	60%	B3.2.1 Shape coefficient (residential)	100%	Shape coefficient > 0,7	Shape coefficient 0,7 – 0,6	Shape coefficient 0,6 – 0,5	Shape coefficient 0,5 – 0,4	Shape coefficient < 0,4
		OR						
		B3.2.1 Shape coefficient (non-res.)	100%	Shape coefficient > 0,5	Shape coefficient 0,5 – 0,4	Shape coefficient 0,4 – 0,3	Shape coefficient 0,3 – 0,25	Shape coefficient < 0,25
		OR						
		B3.2.1 Shape coefficient (residential & non-res.)	100%	Res. > 0,7 Non-res. > 0,5	Res. 0,7 – 0,6 Non-res. 0,5 – 0,4	Res. 0,6 – 0,5 Non-res. 0,4 – 0,3	Res. 0,5 – 0,4 Non-res. 0,3 – 0,25	Res. < 0,4 Non-res. < 0,25
E2 Renewable Energy								
				-2	**-1**	**0**	**+1**	**+2**

E2.1 Potential for future renewable energy production	100%	E2.1 Potential for future renewable energy production	100%	No potential	Potential coverage of total energy demand is 0 – 10 %	Potential coverage of total energy demand is 10 – 20 %	Potential coverage of total energy demand is 20 – 30 %	Potential coverage of total energy demand is > 30 %

Phase 3								
S3 Urban Design								
				-2	**-1**	**0**	**+1**	**+2**
S3.1 Site planning	2%	S3.1.1 Inner city development	10%	Development on agricultural land outside the city	New development of free open space near a sub center (max. 4 km away)	New development of free open space near the city center (max. 3 km away) or near a sub center (max. 2 km away)	Brownfield development near the city center (max. 3 km away) or near a sub center (max. 2 km away)	Brownfield development near the city center (max. 2km away)
		S3.1.2 Integration to the surrounding	45%	Surrounding not covered with buildings	It is planned to cover the surrounding	Surrounding partially (<50%) covered with buildings	Surrounding is covered with buildings (min.50%)	Surrounding is nearly full covered with buildings
		S3.1.3 Regional traffic connection	45%	No regional traffic connection	Partial regional traffic connection	Area wide regional traffic connection by 1 traffic carrier	Area wide regional traffic connection by public transport and individual traffic	Area wide regional traffic connection by individual traffic and different public transport
S3.2 Land use	8%	S3.2.1 Mixture of functions	20%	Monofunctional	2 functions, main function covers min. 80% of the area	2 functions, main function covers min. 50% of the areas	Mixed use exist in some part (near the housing areas)	Mixed use is dominant function in the central part of the area
		S3.2.2 Supplement of existing functions in the surrounding	15%	Conflict with uses in the surrounding	New uses do not fit to the uses in the surrounding	Uses are congruent to the uses in the surrounding	Uses are congruent to the surrounding and enrich them in some parts	New uses enrich the surrounding

		S3.2.3 Maintenance	15%	Large maintenance problems caused by the proposed / existing use	Smaller maintenance problems caused by the proposed / existing use	Basic needs are fulfilled near/within the residential areas	Basic needs are fulfilled close to the residential areas; additional facilities are available nearby	Basic needs are fulfilled in the study area, even for the surrounding area; additional attractions
		S3.2.4 Arrangement of uses	20%	Random allocation of the uses	Central areas have a mixture of functions	Public facilities are located central in the area	Facilities with a lot of occasional customers are located at stops of the public transport	Location of uses is chosen that they complement one another
		S3.2.5 Density allocation population/working opportunities	20%	Population density or density of working opportunities is significantly lower (<90%) than the average density of the city	Population density or density of working opportunities is lower than the average density of the city	Population density or density of working opportunities is similar like the average density of the city	Population density or density of working opportunities is higher than the average density of the city	Population density or density of working opportunities is significantly higher (>110%) than the average density of the city
		S3.2.6 Density allocation building height	10%	Density is significantly lower (<90%) than the average of the city	Density is lower than the average of the city	Density is similar like the average of the city	Density is higher than the average of the city	Density is significantly higher (>110%) than the average of the city
S3.3 Accessibility	30%	S3.3.1 Net of footpaths	5%	Area is not complete equipped with foot paths along the streets	Area is nearly complete equipped with foot paths along the streets	area has footpaths separated from the roads	Short & direct connections to major facilities	links to the surrounding, hierachy of paths
		S3.3.2 Net of cycle tracks	5%	Area is not complete equipped with cycle tracks	Area is nearly complete equipped with cycle tracks along the roads	Area has cycle tracks separated from the roads	Short & direct connections to major facilities by cycle tracks	Links to the surrounding, hierachy of tracks
		S3.3.3 Uses at intersections	10%	Mainly undeveloped areas	No public uses	Few public uses	Private and public uses	Specific attractors
		S3.3.4 Density at important intersections (Building Height)	10%	Very low density	Comparatively low density	Average density of the area	Density slightly above average	Highest density of the area at the nodes and transport hubs
		S3.3.5 Quality of	20%	Paths are too narrow	Paths have sufficient	Tracks along main	In some parts paths	In main parts paths

		footpaths		(<2m), barely usable	width (min. 2m)	roads are separated i.e. by green spaces	have a special design: they are planted, there are some enlargements, there are furniture, tracks have a bright surface	have a special design: they are planted, there are some enlargements, there are furniture, tracks have a bright surface, they are barrier free
		S3.3.6 Quality of cycle tracks	20%	Tracks are too narrow (<2m), barely usable	Tracks have sufficient width (min. 2 m)	Tracks along main roads are separated i.e. by green spaces	In some parts tracks have a special design: they are planted, there are some enlargements, there are furniture, tracks have a bright surface	In main parts tracks have a special design: they are planted, there are some enlargements, there are furniture, tracks have a bright surface
		S3.3.7 Shadow of footpaths	15%	No shadow/no trees	Trees only insular existing	Shadow at up to 50% of the paths	Shadow at more than 50% of the paths	Shadow at more than 80% of the paths
		S3.3.8 Shadow of cycle tracks	15%	No shadow/no trees	Trees only insular existing	Shadow at up to 50% of the tracks	Shadow at more than 50% of the tracks	Shadow at more than 80% of the tracks
S3.4 Public Space	60%	S3.4.1 Existence of public green open space	5%	No public green open space	Narrow green spaces besides the roads	Green open spaces inside the blocks	Min. 1 large green open space (min. 1 ha)	Many green open spaces
		S3.4.2 Location of green open spaces	10%	No green open spaces	Green open spaces only in the outer parts of the area	Green open spaces in the backyards	Green open spaces in the center	Many green open spaces allocated over the area
		S3.4.3 Existence of water surfaces	5%	No water surface	Small water surfaces, above ground rain water drainage	One large water surface (river/lake)	More than one water surface	Many big water surface distributed over the entire area
		S3.4.4 Public spaces/squares	10%	No square	Enlargements at streets can be used as square	One square in the center of the area/next to attractive uses	More than one square allocated over the whole area	More than one square allocated over the whole area with attractive design (furniture,

								shadow by trees, attractive greening)
		S3.4.5 Security	25%	Public space without function, cut off from the rest, small narrow streets, dark zones	Public space poorly accessible and without a clear function, poor lighting	Structured, functional space with security-lighting	Public space accessible with wide pathways and lighting accents to danger spots	Public space especially good designed, good overview, good signage and bright lights at key locations
		S3.4.6 Public accessibility	15%	No access due to lack of connections for pedestrians and cyclists	Access by at least 1 side, links are unattractive	Access by at least 2 sides with some attractive paths	Area is accessible from all sides, quality is not always sufficient	From all sides attractive and barrier-free access
		S3.4.7 Design/Quality	30%	Narrow green spaces besides the roads; without quality	Low amenity values; only grassland	Average amenity values of the public space, low benefit for the inhabitants, low shadow, unattractive footpathes	High amenity values (trees, bushes, attractive footpathes) but only for a few user groups, less flexibility	High amenity values for a lot of user groups and different uses, different design of some areas
M3 Mobility								
				-2	**-1**	**0**	**+1**	**+2**
M3.1 Motorized individual traffic	30%	M3.1.1 Differentiated area-toll	25%	No area toll-concept	Area toll-accessibility-concept for high polluting vehicles or only in several time periods of a day implemented	Area toll-concept for high polluting vehicles implemented	Area toll-concept implemented for all vehicles	Area toll-concept implemented, graded according to CO_2 emission or discount for high occupied vehicles

		M3.1.2 E-mobility, recharging devices or battery switch stations (expected e-mobility rate for in 10 years	25%	No recharging devices / no switch station	Some parking with recharging devices, access only for employee of some companies, private garage owners, or parking pass holders/ next switch station more than 5 km from the area	Some parking with recharging devices, access partially only for employee of some companies, or parking pass holders/ next switch station less than 5 km from the area	Adequate number of parking with recharging devices, access for all / next switch station less than 2 km from the area	Adequate number of parking with recharging devices, access for all / switch stations inside of the area, or at the border - easy payment
		M3.1.3 Car park management system, traffic flow	10%	No concept	Equal parking charge for all vehicles / no traffic flow management	Parking charge partially graded according to CO_2 emission / only few roads with traffic light management	Parking charge graded according to CO_2 emission and parking duration / traffic light management	Parking charge graded according to CO_2 emission and parking duration, with easy payment (e.g. prepaid cards, payment by cell phone) / dynamic demand oriented traffic light management
		M3.1.4 Traffic-calming, speed limit, road space arrangement	15%	No traffic-calming concept, main roads in residential areas	Traffic calming only inside of neighbourhood boundary	Few traffic-calming implemented on public roads	Several traffic-calming implemented on public roads	Good traffic-calming and attractive street furniture
		M3.1.5 Car sharing: 1. cars available in the whole area - not station-bounded; 2. easy registration and payment; 3. online reservation; 4. discount on PT tickets; 5. discount on car-rent (cars and trucks)	25%	No car sharing concept	Car sharing available but no one criterion fulfilled	1 criteria fulfilled	3 criteria fulfilled	All criteria fulfilled

M3.2 Public transport	55%	M3.2.1 Quality of stops: 1. canopy; 2. lighting; 3. barrier-free access; 4. bicycle racks; 5. dynamic passenger information; 6. ticket machine; 7. small scale shopping possibility around the stop	15%	Most of stops don't fulfill any criteria	2 or more criteria fulfilled for several stops	3 or more criteria fulfilled for the most of stops	5 or more criteria fulfilled for the most of stops	All criteria fulfilled for the most of stops
		M3.2.2 Costs for passengers	20%	Commuting by public transport causes much higher costs (> 150%) than gasoline costs of an average car (10 l per 100km)	Commuting by public transport > 100% of gasoline costs of an average car (10 l per 100km)	Commuting by public transport is cheaper than gasoline costs of an average car (10 l per 100km)	Commuting by public transport < 75% of gasoline costs of an average car (10 l per 100km)	Commuting by public transport < 50% of gasoline costs of an average car (10 l per 100km)
		M3.2.3 Comprehensibility of tariff system	10%	Ticket system absolutely difficult to understand; many exceptions	Different tickets for different carriers or lines	Ticket system with many exceptions	Ticket system is understandable	Ticket system very easy to understand; perfect networking of the entire metropolitan, electronic ticketing, discounts for frequent users
		M3.2.4 Speed (commuting during the rush hour)	15%	Travel time public transport much longer as travel time motorized individual traffic	Travel time public transport slightly longer as travel time motorized individual traffic	Travel time public transport almost the same as travel time motorized individual traffic	Travel time public transport slightly shorter as travel time motorized individual traffic	Travel time public transport much shorter as travel time motorized individual traffic
		M3.2.5 Average occupation level of vehicles in the highest peak hour	15%	Higher than 95%, or lower than 5%	Between 85% - 95%, or between 10 - 5%%	Between 75% - 85%, or between 15% - 10%	Between 65% - 75%, or between 20% - 15%	Between 65% and 20%

		M3.2.6 Quality of vehicles: 1. air-condition; 2. kneeling technic; 3. low-floor; 4. wide doors; 5. dynamic passenger information	10%	Most of vehicles don't fulfill any criteria	1 or more criteria fulfilled by several vehicles	2 criteria fulfilled by the most of vehicles	3 criteria fulfilled by the most of vehicles	All criteria fulfilled by the most of vehicles
		M3.2.7 Engine concept for buses (fuel…)	15%	Old combustion engines (diesel / petrol)	Improved old combustion engines (diesel / petrol)	Economical combustion engines (diesel / petrol) or bio-diesel	Economical combustion engines (diesel / petrol) or bio-diesel and electric engines or hybrid	Electric engines or hybrid
M3.3 Goods traffic	15%	M3.3.1 Priorization of low emission vehicles: 1. permission to enter restricted zones; 2. no restriction for delivering time periods; 3. recharging devices in delivering zones; 4. special delivering zones only for this vehicles; 5. area toll discount	100%	No one criterion fulfilled	1 criterion fulfilled	2 criteria fulfilled	3 criteria fulfilled	4 or more criteria fulfilled
B3 Buildings								
				-2	**-1**	**0**	**+1**	**+2**
B3.1 Building environme nt	10%	B3.1.1 Solar orientation	55%	> 25 % of building (blocks) are south-oriented	25 % of building (blocks) are south-oriented	50 % of building (blocks) are south-oriented	75 % of building (blocks) are south-oriented	All building (blocks) are south-oriented
		B3.1.2 Wind exposition	10%	> 25 % of buildings have a wind-exposed location	< 25 % of buildings have a wind-exposed location	Buildings are located on a plain site	< 25 % of buildings have a wind-protected	> 25 % of buildings have a wind-protected

							location	location
		B3.1.3 Wind use for natural ventilation	10%	No Wind Use for Natural Ventilation	20 % Wind Use for Natural Ventilation	40 % Wind Use for Natural Ventilation	60 % Wind Use for Natural Ventilation	> 60 % Wind Use for Natural Ventilation
		B3.1.4 Green elements to reduce heat island effect	15%	None towards facades	0 – 10 % towards facades	10 – 20 % towards facades	20 – 30 % towards facades	> 30 % towards facades
		B3.1.5 Location adjacent green/ water space	10%	No buildings are adjacent green/water space	5% of buildings are adjacent green/water space	10% of buildings are adjacent green/water space	15% of buildings are adjacent green/water space	>15% of buildings are adjacent green/water space
B3.2 Building type	20%	B3.2.1 Shape coefficient (residential)	100%	Shape coefficient > 0,7	Shape coefficient 0,7 – 0,6	Shape coefficient 0,6 – 0,5	Shape coefficient 0,5 – 0,4	Shape coefficient < 0,4
		OR						
		B3.2.1 Shape coefficient (non-res.)	100%	Shape coefficient > 0,5	Shape coefficient 0,5 – 0,4	Shape coefficient 0,4 – 0,3	Shape coefficient 0,3 – 0,25	Shape coefficient < 0,25
		OR						
		B3.2.1 Shape coefficient (residential & non-res.)	100%	Res. > 0,7 Non-res. > 0,5	Res. 0,7 – 0,6 Non-res. 0,5 – 0,4	Res. 0,6 – 0,5 Non-res. 0,4 – 0,3	Res. 0,5 – 0,4 Non-res. 0,3 – 0,25	Res. < 0,4 Non-res. < 0,25
B3.3 Building envelope	35%	B3.3.1 Walls – material/insulation	20%	U-Value > 1,5	U-Value 1,5 – 1,0	U-Value 1 – 0,6	U-Value 0,6 – 0,3	U-Value < 0,3
		B3.3.2 Roof – material/insulation	20%	U-Value > 1	U-Value 0,6 – 1	U-Value 0,3 – 0,6	U-Value 0,2 – 0,3	U-Value < 0,2
		B3.3.3 Windows – material/insulation	20%	Single glazing U-Value 5,7	Double glazing U-Value 4,0	Double insulating glazing U-Value 3,0	Triple insulating glazing U-Value 1,7	Low energy window U-Value < 1,3
		B3.3.4 PEI material/insulation	5%	< 20 % of materials have a low PEI	20 – 40 % % of materials have a low PEI	40 – 60 % % of materials have a low PEI	60 – 80 % % of materials have a low PEI	> 80 % % of materials have a low PEI
		B.3.3.5	5%	N 40%, S 50%, WO	N 35%, S 45%, WO	N 30%, S 40%, WO	N 25%, S 35%, WO	N 20%, S 30%, WO

		Window-ratio		25 %	20 %	15 %	10 %	5 %
		B3.3.6 Sun protection in Summer	15%	No sun protection for windows & facade	Sun protection devices for 25 % of transparent area	Sun protection devices for 50 % of transparent area	Sun protection devices for 75 % of transparent area	Sun protection devices for >75 % of transparent area
		B.3.3.7 Light/Cool facade	8%	All facades have SR < 0,7 and TE < 0,8	20% of facades have SR > 0,7 and TE > 0,8	40% of facades have SR > 0,7 and TE > 0,8	60% of facades have SR > 0,7 and TE > 0,8	>80% of facades have SR > 0,7 and TE > 0,8
		B3.3.8 Green roof	8%	No green roofs	0 – 20 % green roofs	20 – 35 % green roofs	35 – 50 % green roofs	> 50 % green roofs
B3.4 Building technolog y	25%	B3.4.1 Efficiency of heater	35%	> 10 % less efficient than the Standard	0 – 10 % less efficient than the Standard	Complies with Standard	0 – 10 % more efficient than the Standard	>10 % more efficient than the Standard
		B3.4.2 Efficiency of air-conditioner	40%	> 10 % less efficient than the Standard	0 – 10 % less efficient than the Standard	Complies with Standard	0 – 10 % more efficient than the Standard	>10 % more efficient than the
		B3.4.3 Efficiency of ventilation	10%	> 10 % less efficient than the Standard	0 – 10 % less efficient than the Standard	Complies with Standard	0 – 10 % more efficient than the Standard	>10 % more efficient than the
		B.3.4.4 District heating and cooling	10%	No DHC systems	15 % of energy demand is covered by DHC systems	30 % of energy demand is covered by DHC systems	45 % of energy demand is covered by DHC systems	>45 % of energy demand is covered by DHC systems
		B.3.4.5 Energy consumption metering	5%	Sub-metering devices installed at the building/plot level	In addition: 20% of buildings have Smart Meter for individual units/tenants	In addition: 40% of buildings have Smart Meter for individual units/tenants	In addition: 60% of buildings have Smart Meter for individual units/tenants	In addition: >60% of buildings have Smart Meter for individual units/tenants
B3.5 Thermal comfort	10%	B3.5.1 Thermal comfort winter	40%	Inside temp. < 16 °C	Inside temp. 16 – 17 °C	Inside temp. 18 °C	Inside temp. 19 – 20 °C	Inside temp. 21 – 22 °C
		B3.5.2 Thermal comfort summer	45%	Inside temp. > 28 °C	Inside temp. 27 – 28 °C	Inside temp. 26 °C	Inside temp. 24 – 25 °C	Inside temp. < 24 °C
		B3.5.3 Controllability of systems	15%	Comfort controls for < 10% of the building occupants	Comfort controls for 30% of the building occupants	Comfort controls for 50% of the building occupants	Comfort controls for 70% of the building occupants	Comfort controls for > 70% of the building occupants
E3 Renewable Energy								
				-2	**-1**	**0**	**+1**	**+2**

E3.1 Local renewable energy production	70%	E3.1.1 Renewable energy production	95%	No renewable energy production	0 – 2,5 % coverage of energy demand	2,5 – 5 % coverage of Energy demand	5 – 7,5 % coverage of energy demand	> 7,5 % coverage of energy demand
		E3.1.2 Green electricity contract	5%	< -5 % HH with green electricity contract	- 5 % HH with green electricity contract	HH with green electricity contract comply with average	+ 5 % HH with green electricity contract	> 5 % HH with green electricity contract
E3.2 Potential for future renewable energy production	30%	E3.2.1 Potential for future renewable energy production	100%	Covarage of total energy demand is 0 %	Coverage of total energy demand is 0 – 10 %	Coverage of total energy demand is 10 – 20 %	Coverage of total energy demand is 20 – 30 %	Coverage of total energy demand is > 30 %

Appendix 9

Questionnaire Survey of Low-Carbon & Resilience Indicator System

(Round 1)

Thank you for your attention and participation to this questionnaire survey!

This survey is conducted based on the study "Low-Carbon Indicator System – Sino: Evaluating the Low-Carbon City Development Level in China". The aim of the thesis is to develop a low-carbon city evaluation system – Low-Carbon Indicator System – Sino (LCISS) for Chinese cities, in order to provide standards and guidance for low-carbon city development in China. LCISS consists of 3 phases:

- Phase 1: starts with a relatively rough planning stage (level of master plan), at a large scale (1:10,000). Many parameters and information are not yet known. The aim of the Phase 1 evaluation is to make overview the potential deficits of current planning, and suggestions for appropriate strategies to enhance mitigability and adaptability.
- Phase 2: evolves in greater detail (level of regulatory plan), at scale of 1:2,000. It aims at making another overview of the potential deficits and possible optimization.
- Phase 3: works on implementation (level of site plan), at scale of 1:500. Detail planning and work plans are created and further details specified. In this phase, diagnosis of weak point of mitigability and adaptability is made, and feedback loops is created.

For existing urban areas, the Low-Carbon & Resilience Indicator System generally contains all three defined phases. In case of new-developed projects, involved phases could be determined depending on construction situations.

The Low-Carbon & Resilience Indicator System involves six evaluated topics:

- Urban Design: has impact on the generation of CO_2. Besides, it has influence on traveler traffic mode, urban livability, microclimate, and other important factors.
- Transport: is one of the main energy consumers in urban areas, which accounts for 25% of energy-related CO_2 emissions globally.
- Building: consumes around 40% of total primary energy, and is responsible for 30% of the world's annual GHG emissions.
- Energy: The CO_2 emissions from energy system worldwide experienced stable growth in the last decades.
- Water: has the potential to significantly reduce CO_2, because to address water scarcity that exacerbated by climate change, are potentially very energy and carbon intensive.
- Municipal Solid Waste: is rapidly growing source of carbon emissions. It accounts

for 5–10% of CO_2 emissions generated within a city boundary.

In the different phases, the evaluated topics and criteria change. Moreover, the selected topics and criteria of each urban area vary in accordance with its specific environment, society, economy, and culture background.

For each indicator and criteria, assessment ranges from -2 to +2. This makes maximum 5 points available for an evaluation. The assessment is guided by the average of the particular urban area. 0 points are given if the plans are expected to yield average or standard level of mitigability and adaptability. The best possible planning at time of evaluation earns a score of +2. Conversely, if the plan falls toward the bottom of the scale of possible planning, it earns a value of -2.

By applying this indicator system, climatic mitigability and adaptability of an urban area can be calculated, and a series of results and products can be obtained for guiding low-carbon and resilient development.

In order to select the appropriate indicators for every assessing aspect, two rounds of questionnaire survey are planned to carry out. This questionnaire is the first round survey for indicator selection of the study. The result of first questionnaire will be feedback to you and share the findings with you. After that, the second round will be conducted.

For the sake of communicating with you timely about the survey result, please kindly provide the following information. The information you provide in this application form will be treated as strictly confidential.

Name:
E-mail:
Present Unit:

Please tick (√) the indicators from the following table that you think it is representative, data-available, comparable among cities, and can effectively guide a city's low-carbon and resilient development. You may need about 20 minutes to finish the questionnaire.

Assessing Topic	Assessing Aspect	No.	Indicator	Evaluation Content	Selection Rate	Note
Urban Design	Site Planning	1	Inner city development	Distance between the new development and city center /sub center, and original land use type		
		2	Integration to the surrounding	Building coverage of the new development's surrounding		
		3	Disaster risk (e.g. sea-level rise, flooding, landslides or any other risk)	Whether new development is located on high risk area, and level of protective measures		
	Land Use	4	Mixture of functions	Diversity of land use function		
		5	Supplement of existing functions in the surrounding	Relationship between new uses and existing uses in the surrounding (conflict→unfit→congruent→enrich)		
		6	Maintenance	Whether the land use functions can fulfill basic needs		
		7	Arrangement of uses	Rationality of public facilities allocation (random→ mutually complement one another)		
		8	Employment-housing equilibrium index	Percentage of the employable residents in the community/city that are employed in the community/city.		
		9	Urban development land area per capita	Urban development land area of city/ number of permanent resident population in city center		
		10	Small-scale building block /community	Percentage of small-scale building block /community (2-5 ha)		
	Accessibil ity	11	Regional traffic connection	Diversity and type of regional traffic connection		
		12	Transit-oriented employment density	Employments per km^2 within 500m of important stops		
		13	Transit-oriented residential density	Dwelling units per km^2 within 500m of important stops		
		14	Resilience of road infrastructure: 1.More resilient design standards and materials for infrastructure construction 2.Improved drainage systems 3.Regular maintenance 4.Avoid high risk areas 5.Provide sufficient redundancy	Number of criterion fulfilled		
	Open Space	15	Existence of open green space	Percentage of greenery coverage (%)		
		16	Coverage ratio of green space service radius	Park green space service radius of coverage		
		17	Existence of water surfaces	Amount and scale of water surface		
		18	Squares	Amount and scale of square		

Assessing Topic	Assessing Aspect	No.	Indicator	Evaluation Content	Selection Rate	Note
		19	Quality of open space (green spaces/ water spaces/ squares): 1. Equipped with various public facilities (e.g. furniture, toilet, sculpture, landscape decoration, fountain) 2.Plant low water consumption native plants 3.Well functional organized space with different uses 4.Good accessibility 5.Bright lights at key locations 6.Clear signage 7.Well shadowed 8. Applied devices by renewable energy 9. Applied light colored, durable, environmental friendly pavement material	Number of criterion fulfilled		
Suggested Supplement						
Transport	Motorized Individual Transport	20	Position in network of traffic artery	Distance between the new development and the nearest traffic artery		
		21	City-accessibility-concept	Degrees of perfection of access-control in new development. Whether access-control is graded according to CO_2 and pollution emission, and implemented all-weather.		
		22	Local roads for adjacent owners and visitors, restriction for transit traffic	Coverage of local roads		
		23	Congestion of interior road network	Frequency and duration of congestion of interior road network (motorized individual traffic)		
		24	Road network density	Road length per unit of area		
		25	Differentiated area-toll	Degrees of perfection of area-toll regulation in new development. Whether area-toll regulation is graded according to CO_2 and pollution emission, and implemented all-weather.		
		26	Recharging devices of E-mobility	Whether there are adequate numbers of parking with		

Assessing Topic	Assessing Aspect	No.	Indicator	Evaluation Content	Selection Rate	Note
				recharging devices; whether they are accessible for all; whether equipped at PT stops.		
		27	Car park management system	Degrees of perfection of car park management system in new development. Differentiated parking fee graded according to CO_2 and pollution emission of vehicles, and convenient level of payment.		
		28	Traffic-calming, speed limit, road space arrangement	Implementing scope of traffic-calming concept		
		29	Car sharing: 1.Cars available in the whole area - not station-bounded 2.Easy registration and payment 3.Online reservation 4.Discount on PT tickets 5.Discount on car-rent (cars and trucks)	Number of criterion fulfilled		
	Public Transport	30	Connection to fast mass transport	Distance between area center and fast mass transport		
		31	Main form of Mass Rapid Transport	Type of Mass Rapid Transport		
		32	Connection to the major origins and destinations	Coverage of main origins and destinations, and traffic mode of the connection		
		33	Congestion frequency fast PT - metro, tram and BRT with own track (to/from main origin and destination areas)	Frequency and duration of congestion of fast PT		
		34	Transit station coverage	Coverage of stopping points		
		35	Approach to bus on-street priority	Implementing scope of dedicated busways		
		36	Quality of public transport stations: 1. Canopy 2. Ticket machine 3. Passenger travel information 4. Lighting 5. Barrier-free access 6. Bicycle parking infrastructure 7. Small scale shopping possibility nearby	Number of criterion fulfilled		

Assessing Topic	Assessing Aspect	No.	Indicator	Evaluation Content	Selection Rate	Note
		37	Costs for passengers	Ratio of costs commuting by PT to gasoline costs of an average car (10L per 100km)		
		38	Convenience of tariff system	Understandability of tariff system, and convenient level of payment		
		39	Load factors in the highest peak hour	Average occupation level of vehicles in the highest peak hour		
		40	Average wait time in the highest peak hour	Average wait time in the highest peak hour		
		41	Quality of public transport vehicles: 1. Air-condition 2. Wide doors 3. Passenger travel information 4. Entertainments (e.g. TV, internet service)	Number of criterion fulfilled		
		42	Emission level of buses	Emission level of most buses		
	Non-motorized Transport	43	Connectivity of Footpaths	Coverage and accessibility of footpaths		
		44	Quality of footpaths	Width, allocation and design (incl. shadow coverage) of footpaths		
		45	Connectivity of cycle tracks	Coverage and accessibility of f cycle tracks		
		46	Quality of cycle tracks	Width, allocation and design (incl. shadow coverage) of cycle tracks		
		47	Non-motorized vehicle parking: 1.Sufficient parking space at important public service facilities and PT stops 2.Well-equipped bicycle racks and lighting 3.Good security 4.Clear signage	Number of criterion fulfilled		
	Freight Transport	48	Congestion frequency (freight transport)	Frequency of congestion of freight transport (different peak hours as motorized individual traffic)		
		49	Main freight transport modes	Diversity and type of freight transport		
		50	Prioritization of low emission trucks: 1. Subsidies and tax concessions to encourage the purchase and use of low emission vehicles 2. Permission to enter auto restricted zones	Number of criterion fulfilled		

Assessing Topic	Assessing Aspect	No.	Indicator	Evaluation Content	Selection Rate	Note
			3. No restriction for delivering time periods 4. Recharging devices in delivering zones 5. Special delivering zones only for low emission trucks			
Suggested Supplement						
Building	Building Environment	51	Solar orientation	Percentage of south-oriented building		
		52	Location adjacent green/ water space	Percentage of buildings locate adjacent green/water space		
		53	Wind use for natural ventilation	Percentage of wind use for natural ventilation		
		54	**Locally resourced, retrofitted material**	**Percentage of locally resourced, retrofitted material used in buildings**		
	Building Envelope	55	Shape coefficient (residential & non-res.)	Shape coefficient of residential & non-residential building Building shape coefficient is defined as the ratio of building superficial area which contacts the outdoor air and the building volume. S= F0/V0		
		56	Air-tightness	Whether building air-tightness meet the PRC's national standard "Graduations and test methods of air permeability, watertightness, wind load resistance performance for building external windows and doors (GB/T7106-2008)"		
		57	Windows – material/ insulation	Heat transmission coefficient (U value) of windows material		
		58	Window-to- Wall ratio	Window-to- Wall Ratio in building's four directions		
		59	Sun protection in summer	Coverage of sun protection device for transparent area of buildings		
		60	Walls – material/ insulation	Heat transmission coefficient (U value) of walls material		
		61	Vertical greening	Percentage of green facades		
		62	Roof – material/ insulation	Heat transmission coefficient (U value) of roofs material		
		63	Green roof	Percentage of green roofs		
	Building Technology	64	Efficiency of heater	Whether building air-tightness meet the PRC's national standard "Design Standard for Energy Efficiency of Public Buildings (GB 50189-2005)"		
		65	Efficiency of air-conditioner	Whether building air-tightness meet the PRC's national		

Assessing Topic	Assessing Aspect	No.	Indicator	Evaluation Content	Selection Rate	Note
				standard "Design Standard for Energy Efficiency of Public Buildings (GB 50189-2005)"		
		66	Efficiency of ventilation	Whether building air-tightness meet the PRC's national standard "Design Standard for Energy Efficiency of Public Buildings (GB 50189-2005)"		
		67	Efficiency of illumination	Whether building air-tightness meet the PRC's national standard "Standard for Lighting Design of Buildings (GB 50034-2004)"		
		68	Energy consumption metering	Percentage of buildings have smart meter for individual units/tenants		
Suggested Supplement						
Energy	Supply-side	69	Renewable energy production	Coverage of user's energy demand		
		70	Electricity production by co-generation	(power generated by co-generation system /total power consumption) *100%		
	Demand-side	71	Green electricity contract	Whether have green electricity products Green electricity program refers to utilities purchase or generate renewable-sourced electricity, and offers it as a distinct product to users. The end users have the option to purchase and use part or all of their electricity from the green sources.		
		72	Metered heating rate	Percentage of buildings have heating meter for individual units/tenant and being billed by the meter		
		73	Controllability of heating systems	Percentage of users that have controllable heating systems		
Suggested Supplement						
Water & Waste Water	Water Supply	74	Water supply from non-traditional sources (reclaimed water, rainwater, etc.)	Percentage of water supply from non-traditional sources, such as recycled water, rain water, desalinated sweater, etc.		
		75	Water tariff	Whether water tariffs cascading is implemented, how is the charging rate, and. whether the waste treatment cost is inclusive.		

Assessing Topic	Assessing Aspect	No.	Indicator	Evaluation Content	Selection Rate	Note
		76	Leakage rate	proportion of water leaking from pipes out of the overall amount of water distributed to households and other properties		
	Wastewater Treatment	77	Site planning of wastewater treatment plants	Whether the wastewater treatment plants are away from surface water supplies or flood plains		
		78	Treatment rate of wastewater	Percentage of wastewater treated		
	Storage and Drainage	79	Stormwater and wastewater diversion	Whether stormwater and wastewater diversion is implemented		
		80	Coverage of drainage network	Coverage of drainage network		
		81	Drainage system	Performance of drainage system		
		82	Flood protection	Whether have a sound early-warning and emergency response system		
Suggested Supplement						
MSW	MSW Collection & Transfer	83	Waste collection rate	Percentage of waste collected		
		84	Waste recycling rate	Percentage of waste that is recycled		
		85	Separate waste collection	Percentage of block/community implemented separate waste collection		
		86	Storage system of waste: 1.Corrosive-resistant 2.Lidded 3.Good sealing 4.Away from water sources 5.Away from schools, kindergarten	Number of criterion fulfilled		
		87	Waste management route	Whether the waste management routes are away from surface water supplies or flood plains, and the accessibility		
	MSW Disposal	88	Harmless treatment rate	Percentage of waste that rendered non-toxic treatment		
		89	Landfilling rate	Percentage of waste treated by incineration		
Suggested Supplement						

Thank you very much for contribution to this study. If you have any problems, or any comments and suggestions in this process, please feel free to contact us.

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Appendix 10

Questionnaire Survey of Low-Carbon Indicator System – Sino (Round 2)

Thank you for your attention and participation to this questionnaire survey!

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- Phase 1: starts with a relatively rough planning stage (level of master plan), at a large scale (1:10,000). Many parameters and information are not yet known. The aim of the Phase 1 evaluation is to make overview the potential deficits of current planning, and suggestions for appropriate strategies to enhance mitigability and adaptability.
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For existing urban areas, the Low-Carbon & Resilience Indicator System generally contains all three defined phases. In case of new-developed projects, involved phases could be determined depending on construction situations.

The Low-Carbon & Resilience Indicator System involves six evaluated topics:

- Urban Design: has impact on the generation of CO_2. Besides, it has influence on traveler traffic mode, urban livability, microclimate, and other important factors.
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- Building: consumes around 40% of total primary energy, and is responsible for 30% of the world's annual GHG emissions.
- Energy: The CO_2 emissions from energy system worldwide experienced stable growth in the last decades.
- Water: has the potential to significantly reduce CO_2, because to address water scarcity that exacerbated by climate change, are potentially very energy and carbon intensive.
- Municipal Solid Waste: is rapidly growing source of carbon emissions. It accounts for 5–10% of CO_2 emissions generated within a city boundary.

In the different phases, the evaluated topics and criteria change. Moreover, the selected topics and criteria of each urban area vary in accordance with its specific environment, society, economy, and culture background.

For each indicator and criteria, assessment ranges from -2 to +2. This makes maximum 5 points available for an evaluation. The assessment is guided by the average of the particular urban area. 0 points are given if the plans are expected to yield average or standard level of mitigability and adaptability. The best possible planning at time of evaluation earns a score of +2. Conversely, if the plan falls toward the bottom of the scale of possible planning, it earns a value of -2.

By applying this indicator system, climatic mitigability and adaptability of an urban area can be calculated, and a series of results and products can be obtained for guiding low-carbon and resilient development.

In order to select the appropriate indicators for every assessing aspect, two rounds of questionnaire survey are planned to carry out. The first round survey has been finished in Feb. 2014, and got supports from 31 experts. The result of first questionnaire is shown as feedback in this questionnaire (round 2). For the further study, we cordially invite you to take part in the second round survey.

For the sake of communicating with you timely about the survey result, please kindly provide the following information. The information you provide in this application form will be treated as strictly confidential.

Name:
E-mail:
Present Unit:

Please tick (√) the indicators from the following table that you think it is representative, data-available, comparable among cities, and can effectively guide a city's low-carbon and resilient development. You may need about 25 minutes to finish the questionnaire.

Notes:
1. At least one indicator under each assessing aspect should not be chosen.
2. Indicators marked in bold are modified indicators of the original ones. If you think this indicator should be chosen, please choose only one from either the original (e.g. 2a) or the modified indicators (e.g. 2b).
3. Indicators shown in italic are newly suggested indicators.

Assessing Topic	Assessing Aspect	No.	Indicator	Evaluation Content	Indicator selection rate/ Suggested indicator occurrence	Note
Urban Design	Site Planning	1	Inner city development	Distance between the new development and city center /sub center, and original land use type	80%	
		2	Integration to the surrounding	Building coverage of the new development's surrounding	37%	
		3	Disaster risk (e.g. sea-level rise, flooding, landslides or any other risk)	Whether new development is located on high risk area, and level of protective measures	70%	
	Land Use	4	Mixture of functions	Diversity of land use function	83%	
		5	Supplement of existing functions in the surrounding	Relationship between new uses and existing uses in the surrounding (conflict→unfit→congruent→enrich)	73%	
		6	Maintenance	Whether the land use functions can fulfill basic needs	47%	
		7	Arrangement of uses	Rationality of public facilities allocation (random→ mutually complement one another)	47%	
		8	Employment-housing equilibrium index	Percentage of the employable residents in the community/city that are employed in the community/city.	73%	
		9	Urban development land area per capita	Urban development land area of city/ number of permanent resident population in city center	60%	
		10	Small-scale building block /community	Percentage of small-scale building block /community (2-5 ha)	67%	
	Accessibility	11	Regional traffic connection	Diversity and type of regional traffic connection	90%	
		12	Transit-oriented employment density	Employments per km^2 within 500m of important stops	93%	
		13	Transit-oriented residential density	Dwelling units per km^2 within 500m of important stops	97%	
		14	Resilience of road infrastructure: 1.More resilient design standards and materials for infrastructure construction 2.Improved drainage systems 3.Regular maintenance 4.Avoid high risk areas 5.Provide sufficient redundancy	Number of criterion fulfilled	50%	
	Open	15a	Existence of open green space	Percentage of greenery coverage (%)	93%	

Assessing Topic	Assessing Aspect	No.	Indicator	Evaluation Content	Indicator selection rate/ Suggested indicator occurrence	Note
	Space	**15b**	**Existence of open green space**	**Open green space area per capita (m^2 per capita)**	1	
		16	Coverage ratio of green space service radius	Park green space service radius of coverage	77%	
		17	Existence of water surfaces	Amount and scale of water surface	60%	
		18	Squares	Amount and scale of square	50%	
		19	Quality of open space (green spaces/ water spaces/ squares): 1. Equipped with various public facilities (e.g. furniture, toilet, sculpture, landscape decoration, fountain) 2.Plant low water consumption native plants 3.Well functional organized space with different uses 4.Good accessibility 5.Bright lights at key locations 6.Clear signage 7.Well shadowed 8. Applied devices by renewable energy 9. Applied light colored, durable, environmental friendly pavement material	Number of criterion fulfilled	83%	
Suggested Supplement			*Community-based green space*	*Percentage of community-based green space in total green open space*	1	
Transport	Motorized Individual Transport	20	Position in network of traffic artery	Distance between the new development and the nearest traffic artery	63%	
		21	City-accessibility-concept	Degrees of perfection of access-control in new development. Whether access-control is graded according to CO_2 and pollution emission, and implemented all-weather.	60%	
		22a	Local roads for adjacent owners and visitors, restriction for transit traffic	Coverage of local roads	33%	
		22b	**Multidirectional street grid**	**Coverage of multidirectional street grid**	1	

Assessing Topic	Assessing Aspect	No.	Indicator	Evaluation Content	Indicator selection rate/ Suggested indicator occurrence	Note
		23	Congestion of interior road network	Frequency and duration of congestion of interior road network (motorized individual traffic)	73%	
		24	Road network density	Road length per unit of area	67%	
		25	Differentiated area-toll	Degrees of perfection of area-toll regulation in new development. Whether area-toll regulation is graded according to CO_2 and pollution emission, and implemented all-weather.	60%	
		26	Recharging devices of E-mobility	Whether there are adequate numbers of parking with recharging devices; whether they are accessible for all; whether equipped at PT stops.	80%	
		27	Car park management system	Degrees of perfection of car park management system in new development. Differentiated parking fee graded according to CO_2 and pollution emission of vehicles, and convenient level of payment.	77%	
		28	Traffic-calming, speed limit, road space arrangement	Implementing scope of traffic-calming concept	43%	
		29	Car sharing: 1.Cars available in the whole area - not station-bounded 2.Easy registration and payment 3.Online reservation 4.Discount on PT tickets 5.Discount on car-rent (cars and trucks)	Number of criterion fulfilled	77%	
	Public Transport	30	Connection to fast mass transport	Distance between area center and fast mass transport	93%	
		31	Main form of Mass Rapid Transport	Type of Mass Rapid Transport	53%	
		32	Connection to the major origins and destinations	Coverage of main origins and destinations, and traffic mode of the connection	70%	
		33	Congestion frequency fast PT - metro, tram and BRT with own track (to/from main origin and destination areas)	Frequency and duration of congestion of fast PT	57%	

Assessing Topic	Assessing Aspect	No.	Indicator	Evaluation Content	Indicator selection rate/ Suggested indicator occurrence	Note
		34	Transit station coverage	Coverage of stopping points	90%	
		35	Approach to bus on-street priority	Implementing scope of dedicated busways	77%	
		36	Quality of public transport stations: 1. Canopy 2. Ticket machine 3. Passenger travel information 4. Lighting 5. Barrier-free access 6. Bicycle parking infrastructure 7. Small scale shopping possibility nearby	Number of criterion fulfilled	70%	
		37	Costs for passengers	Ratio of costs commuting by PT to gasoline costs of an average car (10L per 100km)	53%	
		38	Convenience of tariff system	Understandability of tariff system, and convenient level of payment	47%	
		39	Load factors in the highest peak hour	Average occupation level of vehicles in the highest peak hour	50%	
		40	Average wait time in the highest peak hour	Average wait time in the highest peak hour	70%	
		41	Quality of public transport vehicles: 1. Air-condition 2. Wide doors 3. Passenger travel information 4. Entertainments (e.g. TV, internet service)	Number of criterion fulfilled	60%	
		42	Emission level of buses	Emission level of most buses	77%	
	Non-motorized Transport	43	Connectivity of Footpaths	Coverage and accessibility of footpaths	97%	
		44	Quality of footpaths	Width, allocation and design (incl. shadow coverage) of footpaths	80%	
		45	Connectivity of cycle tracks	Coverage and accessibility of f cycle tracks	97%	
		46	Quality of cycle tracks	Width, allocation and design (incl. shadow coverage) of cycle tracks	80%	

Assessing Topic	Assessing Aspect	No.	Indicator	Evaluation Content	Indicator selection rate/ Suggested indicator occurrence	Note
		47	Non-motorized vehicle parking: 1.Sufficient parking space at important public service facilities and PT stops 2.Well-equipped bicycle racks and lighting 3.Good security 4.Clear signage	Number of criterion fulfilled	77%	
	Freight Transport	48	Congestion frequency (freight transport)	Frequency of congestion of freight transport (different peak hours as motorized individual traffic)	70%	
		49	Main freight transport modes	Diversity and type of freight transport	73%	
		50	Prioritization of low emission trucks: 1. Subsidies and tax concessions to encourage the purchase and use of low emission vehicles 2. Permission to enter auto restricted zones 3. No restriction for delivering time periods 4. Recharging devices in delivering zones 5. Special delivering zones only for low emission trucks	Number of criterion fulfilled	77%	
Suggested Supplement			*Engine concept for freight vehicle*	*Engine type of most freight vehicles (diesel/petrol, bio-diesel, hybrid, electric, natural gas)*	1	
Building	Building Environment	51	Solar orientation	Percentage of south-oriented building	73%	
		52	Location adjacent green/ water space	Percentage of buildings locate adjacent green/water space	67%	
		53	Wind use for natural ventilation	Percentage of wind use for natural ventilation	83%	
		54	Locally resourced, retrofitted material	Percentage of locally resourced, retrofitted material used in buildings	80%	
	Building Envelope	55	Shape coefficient (residential & non-res.)	Shape coefficient of residential & non-residential building Building shape coefficient is defined as the ratio of building superficial area which contacts the outdoor air and the building volume. S= F0/V0	73%	
		56	Air-tightness	Whether building air-tightness meet the PRC's national	83%	

Assessing Topic	Assessing Aspect	No.	Indicator	Evaluation Content	Indicator selection rate/ Suggested indicator occurrence	Note
				standard "Graduations and test methods of air permeability, watertightness, wind load resistance performance for building external windows and doors (GB/T7106-2008)"		
		57	Windows – material/ insulation	Heat transmission coefficient (U value) of windows material	87%	
		58	Window-to- Wall ratio	Window-to- Wall Ratio in building's four directions	67%	
		59	Sun protection in summer	Coverage of sun protection device for transparent area of buildings	80%	
		60	Walls – material/ insulation	Heat transmission coefficient (U value) of walls material	87%	
		61	Vertical greening	Percentage of green facades	67%	
		62	Roof – material/ insulation	Heat transmission coefficient (U value) of roofs material	83%	
		63	Green roof	Percentage of green roofs	83%	
	Building Technolog y	64	Efficiency of heater	Whether building air-tightness meet the PRC's national standard "Design Standard for Energy Efficiency of Public Buildings (GB 50189-2005)"	87%	
		65	Efficiency of air-conditioner	Whether building air-tightness meet the PRC's national standard "Design Standard for Energy Efficiency of Public Buildings (GB 50189-2005)"	83%	
		66	Efficiency of ventilation	Whether building air-tightness meet the PRC's national standard "Design Standard for Energy Efficiency of Public Buildings (GB 50189-2005)"	80%	
		67	Efficiency of illumination	Whether building air-tightness meet the PRC's national standard "Standard for Lighting Design of Buildings (GB 50034-2004)"	73%	
		68	Energy consumption metering	Percentage of buildings have smart meter for individual units/tenants	77%	
Energy	Supply-si de	69	Renewable energy production	Coverage of user's energy demand	93%	
		70	Electricity production by co-generation	(power generated by co-generation system /total power consumption) *100%	83%	

Assessing Topic	Assessing Aspect	No.	Indicator	Evaluation Content	Indicator selection rate/ Suggested indicator occurrence	Note
	Demand-side	71	Green electricity contract	Whether have green electricity products Green electricity program refers to utilities purchase or generate renewable-sourced electricity, and offers it as a distinct product to users. The end users have the option to purchase and use part or all of their electricity from the green sources.	63%	
		72	Metered heating rate	Percentage of buildings have heating meter for individual units/tenant and being billed by the meter	87%	
		73	Controllability of heating systems	Percentage of users that have controllable heating systems	77%	
Suggested Supplement			*Main sources of energy supply*	*Diversity and type of energy sources*	2	
			Incentive policy of renewable energy	*Whether there is existence of policies encouraging the use of renewable energy*	1	
Water & Waste Water	Water Supply	74	Water supply from non-traditional sources (reclaimed water, rainwater, etc.)	Percentage of water supply from non-traditional sources, such as recycled water, rain water, desalinated sweater, etc.	97%	
		75	Water tariff	Whether water tariffs cascading is implemented, how is the charging rate, and. whether the waste treatment cost is inclusive.	77%	
		76	Leakage rate	proportion of water leaking from pipes out of the overall amount of water distributed to households and other properties	77%	
	Wastewater Treatment	77	Site planning of wastewater treatment plants	Whether the wastewater treatment plants are away from surface water supplies or flood plains	50%	
		78	Treatment rate of wastewater	Percentage of wastewater treated	90%	
	Storage and Drainage	79	Stormwater and wastewater diversion	Whether stormwater and wastewater diversion is implemented	80%	
		80	Coverage of drainage network	Coverage of drainage network	43%	
		81	Drainage system	Performance of drainage system	90%	
		82	Flood protection	Whether have a sound early-warning and emergency response system	73%	
Suggested Supplement			*Coverage of water-saving appliances*	*Use rate of water-saving appliances*	2	

Assessing Topic	Assessing Aspect	No.	Indicator	Evaluation Content	Indicator selection rate/ Suggested indicator occurrence	Note
MSW	MSW Collection & Transfer	83	Waste collection rate	Percentage of waste collected	90%	
		84	Waste recycling rate	Percentage of waste that is recycled	93%	
		85	Separate waste collection	Percentage of block/community implemented separate waste collection	87%	
		86	Storage system of waste: 1.Corrosive-resistant 2.Lidded 3.Good sealing 4.Away from water sources 5.Away from schools, kindergarten	Number of criterion fulfilled	53%	
		87	Waste management route	Whether the waste management routes are away from surface water supplies or flood plains, and the accessibility	50%	
	MSW Disposal	88	Harmless treatment rate	Percentage of waste that rendered non-toxic treatment	83%	
		89	Landfilling rate	Percentage of waste treated by incineration	83%	
Suggested Supplement			*Emission level of waste transport vehicles*	*Emission level of most waste transport vehicles*	1	
			Waste disposal fee	*Whether the charge standard is higher than the cost*	1	

Thank you very much for contribution to this study. If you have any problems, or any comments and suggestions in this process, please feel free to contact us.

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Appendix 11

The result of 2nd round survey

First-class indicator	Second-class indicator	No.	Third-class indicator	Evaluation content	Selection rate
Urban Design	Site Planning	1	Inner city development	Distance between the new development and city center /sub center, and original land use type	84%
		2	Integration to the surrounding	Building coverage of the new development's surrounding	24%
		3	Disaster risk (e.g. sea-level rise, flooding, landslides or any other risk)	Whether new development is located on high risk area, and level of protective measures	52%
	Land Use	4	Mixture of functions	Diversity of land use function	96%
		5	Supplement of existing functions in the surrounding	Relationship between new uses and existing uses in the surrounding (conflict→unfit→congruent→enrich)	76%
		6	Maintenance	Whether the land use functions can fulfill basic needs	48%
		7	Arrangement of uses	Rationality of public facilities allocation (random→ mutually complement one another)	48%
		8	Employment-housing equilibrium index	Percentage of the employable residents in the community/city that are employed in the community/city.	92%
		9	Urban development land area per capita	Urban development land area of city/ number of permanent resident population in city center	60%
		10	Small-scale building block /community	Percentage of small-scale building block /community (2-5 ha)	52%
	Accessibility	11	Regional traffic connection	Diversity and type of regional traffic connection	96%
		12	Transit-oriented employment density	Employments per km^2 within 500m of important stops	68%
		13	Transit-oriented residential density	Dwelling units per km^2 within 500m of important stops	64%
		14	Resilience of road infrastructure: 1.More resilient design standards and materials for infrastructure construction 2.Improved drainage systems	Number of criterion fulfilled	40%

First-class indicator	Second-class indicator	No.	Third-class indicator	Evaluation content	Selection rate
			3.Regular maintenance 4.Avoid high risk areas 5.Provide sufficient redundancy		
	Open Space	15	Existence of open green space	Percentage of greenery coverage (%)	68%
		modified indicator	**Existence of open green space**	**Open green space area per capita (m^2 per capita)**	32%
		16	Coverage ratio of green space service radius	Park green space service radius of coverage	76%
		17	Existence of water surfaces	Amount and scale of water surface	60%
		18	Squares	Amount and scale of square	52%
		19	Quality of open space (green spaces/ water spaces/ squares): 1. Equipped with various public facilities (e.g. furniture, toilet, sculpture, landscape decoration, fountain) 2.Plant low water consumption native plants 3.Well functional organized space with different uses 4.Good accessibility 5.Bright lights at key locations 6.Clear signage 7.Well shadowed 8. Applied devices by renewable energy 9. Applied light colored, durable, environmental friendly pavement material	Number of criterion fulfilled	96%
Suggested Supplement			Community-based green space	Percentage of community-based green space in total green open space	36%
Transport	Motorized Individual Transport	20	Position in network of traffic artery	Distance between the new development and the nearest traffic artery	60%
		21	City-accessibility-concept	Degrees of perfection of access-control in new development. Whether access-control is graded according to CO_2 and pollution emission, and implemented all-weather.	52%
		22	Local roads for adjacent owners and visitors, restriction for transit traffic	Coverage of local roads	28%

First-class indicator	Second-class indicator	No.	Third-class indicator	Evaluation content	Selection rate
		23	Congestion of interior road network	Frequency and duration of congestion of interior road network (motorized individual traffic)	68%
		24	Road network density	Road length per unit of area	88%
		25	Differentiated area-toll	Degrees of perfection of area-toll regulation in new development. Whether area-toll regulation is graded according to CO_2 and pollution emission, and implemented all-weather.	56%
		26	Recharging devices of E-mobility	Whether there are adequate numbers of parking with recharging devices; whether they are accessible for all; whether equipped at PT stops.	88%
		27	Car park management	Degrees of perfection of car park management system in new development. Differentiated parking fee graded according to CO_2 and pollution emission of vehicles, and convenient level of payment.	72%
		28	Traffic-calming, speed limit, road space arrangement	Implementing scope of traffic-calming concept	32%
		29	Car sharing: 1.Cars available in the whole area - not station-bounded 2.Easy registration and payment 3.Online reservation 4.Discount on PT tickets 5.Discount on car-rent (cars and trucks)	Number of criterion fulfilled	52%
	Public Transport	30	Connection to fast mass transport	Distance between area center and fast mass transport	84%
		31	Main form of Mass Rapid Transport	Type of Mass Rapid Transport	44%
		32	Connection to the major origins and destinations	Coverage of main origins and destinations, and traffic mode of the connection	60%
		33	Congestion frequency fast PT - metro, tram and BRT with own track (to/from main origin and destination areas)	Frequency and duration of congestion of fast PT	56%
		34	Transit station coverage	Coverage of stopping points	88%
		35	Approach to bus on-street priority	Implementing scope of dedicated busways	80%
		36	Quality of public transport stations: 1. Canopy	Number of criterion fulfilled	64%

First-class indicator	Second-class indicator	No.	Third-class indicator	Evaluation content	Selection rate
			2. Ticket machine 3. Passenger travel information 4. Lighting 5. Barrier-free access 6. Bicycle parking infrastructure 7. Small scale shopping possibility nearby		
		37	Costs for passengers	Ratio of costs commuting by PT to gasoline costs of an average car (10L per 100km)	48%
		38	Convenience of tariff system	Understandability of tariff system, and convenient level of payment	32%
		39	Load factors in the highest peak hour	Average occupation level of vehicles in the highest peak hour	40%
		40	Average wait time in the highest peak hour	Average wait time in the highest peak hour	56%
		41	Quality of public transport vehicles: 1. Air-condition 2. Wide doors 3. Passenger travel information 4. Entertainments (e.g. TV, internet service)	Number of criterion fulfilled	72%
		42	Emission level of buses	Emission level of most buses	72%
	Non-motorized Transport	43	Connectivity of Footpaths	Coverage and accessibility of footpaths	72%
		44	Quality of footpaths	Width, allocation and design (incl. shadow coverage) of footpaths	60%
		45	Connectivity of cycle tracks	Coverage and accessibility of f cycle tracks	72%
		46	Quality of cycle tracks	Width, allocation and design (incl. shadow coverage) of cycle tracks	60%
		47	Non-motorized vehicle parking: 1.Sufficient parking space at important public service facilities and PT stops 2.Well-equipped bicycle racks and lighting 3.Good security 4.Clear signage	Number of criterion fulfilled	80%
	Freight Transport	48	Congestion frequency (freight transport)	Frequency of congestion of freight transport (different peak hours as motorized individual traffic)	32%
		49	Main freight transport modes	Diversity and type of freight transport	52%
		50	Prioritization of low emission trucks:	Number of criterion fulfilled	44%

First-class indicator	Second-class indicator	No.	Third-class indicator	Evaluation content	Selection rate
			1. Subsidies and tax concessions to encourage the purchase and use of low emission vehicles 2. Permission to enter auto restricted zones 3. No restriction for delivering time periods 4. Recharging devices in delivering zones 5. Special delivering zones only for low emission trucks		
Suggested Supplement			Multidirectional street grid	Coverage of multidirectional street grid	32%
			Engine concept for freight vehicle	Engine type of most freight vehicles (diesel/petrol, bio-diesel, hybrid, electric, natural gas)	44%
Building	Building Environment	51	Solar orientation	Percentage of south-oriented building	52%
		52	Location adjacent green/ water space	Percentage of buildings locate adjacent green/water space	48%
		53	Wind use for natural ventilation	Percentage of wind use for natural ventilation	88%
		54	Locally resourced, retrofitted material	Percentage of locally resourced, retrofitted material used in buildings	52%
	Building Envelope	55	Shape coefficient (residential & non-res.)	Shape coefficient of residential & non-residential building Building shape coefficient is defined as the ratio of building superficial area which contacts the outdoor air and the building volume. S= F0/V0	64%
		56	Air-tightness	Whether building air-tightness meet the PRC's national standard "Graduations and test methods of air permeability, watertightness, wind load resistance performance for building external windows and doors (GB/T7106-2008)"	80%
		57	Windows – material/ insulation	Heat transmission coefficient (U value) of windows material	84%
		58	Window-to- Wall ratio	Window-to- Wall Ratio in building's four directions	60%
		59	Sun protection in summer	Coverage of sun protection device for transparent area of buildings	68%
		60	Walls – material/ insulation	Heat transmission coefficient (U value) of walls material	76%
		61	Vertical greening	Percentage of green facades	48%
		62	Roof – material/ insulation	Heat transmission coefficient (U value) of roofs material	80%
		63	Green roof	Percentage of green roofs	72%
	Building Technology	64	Efficiency of heater	Whether building air-tightness meet the PRC's national standard "Design Standard for Energy Efficiency of Public Buildings (GB 50189-2005)"	84%
		65	Efficiency of air-conditioner	Whether building air-tightness meet the PRC's national standard "Design	80%

First-class indicator	Second-class indicator	No.	Third-class indicator	Evaluation content	Selection rate
				Standard for Energy Efficiency of Public Buildings (GB 50189-2005)"	
		66	Efficiency of ventilation	Whether building air-tightness meet the PRC's national standard "Design Standard for Energy Efficiency of Public Buildings (GB 50189-2005)"	76%
		67	Efficiency of illumination	Whether building air-tightness meet the PRC's national standard "Standard for Lighting Design of Buildings (GB 50034-2004)"	72%
		68	Energy consumption metering	Percentage of buildings have smart meter for individual units/tenants	76%
Energy	Supply-side	69	Renewable energy production	Coverage of user's energy demand	88%
		70	Electricity production by co-generation	(power generated by co-generation system /total power consumption) *100%	84%
	Demand-side	71	Green electricity contract	Whether have green electricity products Green electricity program refers to utilities purchase or generate renewable-sourced electricity, and offers it as a distinct product to users. The end users have the option to purchase and use part or all of their electricity from the green sources.	56%
		72	Metered heating rate	Percentage of buildings have heating meter for individual units/tenant and being billed by the meter	76%
		73	Controllability of heating systems	Percentage of users that have controllable heating systems	64%
Suggested Supplement			Main sources of energy supply	Diversity and type of energy sources	68%
			Incentive policy of renewable energy	Whether there is existence of policies encouraging the use of renewable energy	80%
Water & Waste Water	Water Supply	74	Water supply from non-traditional sources (reclaimed water, rainwater, etc.)	Percentage of water supply from non-traditional sources, such as recycled water, rain water, desalinated sweater, etc.	92%
		75	Water tariff	Whether water tariffs cascading is implemented, how is the charging rate, and. whether the waste treatment cost is inclusive.	80%
		76	Leakage rate	proportion of water leaking from pipes out of the overall amount of water distributed to households and other properties	84%
	Wastewater Treatment	77	Site planning of wastewater treatment plants	Whether the wastewater treatment plants are away from surface water supplies or flood plains	48%
		78	Treatment rate of wastewater	Percentage of wastewater treated	96%
	Storage and Drainage	79	Stormwater and wastewater diversion	Whether stormwater and wastewater diversion is implemented	92%
		80	Coverage of drainage network	Coverage of drainage network	44%
		81	Drainage system	Performance of drainage system	92%
		82	Flood protection	Whether have a sound early-warning and emergency response system	68%

First-class indicator	Second-class indicator	No.	Third-class indicator	Evaluation content	Selection rate
Suggested Supplement			Coverage of water-saving appliances	Use rate of water-saving appliances	64%
MSW	MSW Collection & Transfer	83	Waste collection rate	Percentage of waste collected	92%
		84	Waste recycling rate	Percentage of waste that is recycled	92%
		85	Proportion of communities with separate waste collection facilities	Percentage of block/community implemented separate waste collection	84%
		86	Storage system of waste: 1.Corrosive-resistant 2.Lidded 3.Good sealing 4.Away from water sources 5.Away from schools, kindergarten	Number of criterion fulfilled	40%
		87	Waste management route	Whether the waste management routes are away from surface water supplies or flood plains, and the accessibility	48%
	MSW Disposal	88	Harmless treatment rate	Percentage of waste that rendered non-toxic treatment	84%
		89	Landfilling rate	Percentage of waste treated by incineration	68%
Suggested Supplement			Emission level of waste transport vehicles	Emission level of most waste transport vehicles	64%
			Waste disposal fee	Whether the charge standard is higher than the cost	40%

Appendix 12

Indicators of urban design in LCISS

First-class indicator	Second-class indicator	No.	Indicator	Evaluation scale				
				-2	-1	0	+1	+2
Urban design	Site planning	1	Original land use type	Arable land / woodland / grassland		Unused land		Brownfield
		2	Disaster risk	There are constructions in high risk areas that threated by disasters, such as flood, geologic hazard, and secondary disaster				There is no construction in high risk areas that threated by disasters, geologic hazard, or secondary disaster.
	Land use	3	Mixture of functions	D<0.980	0.980≤D≤0.988	D=0.990	0.992≤D≤0.994	0.995≤D
				or				
				≤3 types of diverse uses	4-6 types of diverse uses	7-10 types of diverse uses	11-18 types of diverse uses	≥19 types of diverse uses / >10 types of diverse uses and employment-housing equilibrium index >50%
		4	Urban development land area per capita	Higher than the standard stated in the PRC's National Standard GB 50137-2011		Compliance with the standard stated in the PRC's National Standard GB 50137-2011		Lower than the standard stated in the PRC's National Standard GB 50137-2011
		5	Small-scale block	R<40%	40%≤R<50%	50%≤R<70%	70%≤R<80%	80%≤R

	Accessibility	6	Regional traffic connection	No regional traffic connection	Partial regional traffic connection	Area wide regional traffic connection only by individual transport	Area wide regional traffic connection by individual transport and one kind of public transport	Area wide regional traffic connection by individual transport and various public transport
		7	Transit-oriented employment density	Lowest density of the area at public transport hubs	Density slightly below average	Average density of the area	Density slightly above average	Highest density of the area at public transport hubs
		8	Transit-oriented residential density	Lowest density of the area at public transport hubs	Density slightly below average	Average density of the area	Density slightly above average	Highest density of the area at public transport hubs
	Green open space	9	Greenery coverage ratio	>20% than the average level	≤20% below the average level	Similar like the average level	≤20% above the average level	>20% above the average level
		10	Coverage ratio of park green space service radius	R<60%	60%≤R<70%	70%≤R<80%	80%≤R<90%	90%≤R
		11	Quality of green open space: 1. Equipped with various public facilities (e.g. furniture, sculpture, landscape decoration, fountain) 2.Plant low water consumption native plants 3.Well functional organized space with different uses 4.Good accessibility 5.Bright lights at key locations 6.Clear signage 7.Well shadowed 8. Applied devices by renewable energy 9. Applied light colored, durable, environmental	No one criterion fulfilled	1-2 criterion fulfilled	3-4 criteria fulfilled	5-6 criteria fulfilled	All criteria fulfilled

			friendly pavement material					

Indicators of transport in LCISS

Transport	Motorized Individual Transport	1	Position in highway network	Long distance (≥ 5km) to the next highway	Next highway < 5km away from the border	Next highway < 2km away from the border	Next highway < 1km away from the border	Highway inside of the area, or along of a border
		2	Road network density	Below the standard, and branch roads account lower proportion of total length of network	Below the standard	Complies with Standard	Above the standard	Above the standard, and branch roads account higher proportion of total length of network
		3	Car park management	No local law, regulation and policy of car park management		Local laws, regulations and policies of car park management are being developed		Local laws, regulations and policies of car park management have been implemented
		4	Recharging devices of E-mobility	No recharging device	Some parking with recharging devices, access only for employee of some companies, private garage owners, or parking pass holders	Some parking with recharging devices, access for all	Adequate number of parking with recharging devices, access for all	Adequate number of parking with recharging devices, access for all; and combined with transport connection point, easy payment
		5	Car-sharing: 1. Cars available in the whole area - not station-bounded 2.Easy registration and payment 3.Online reservation 4. Discount on public transport tickets 5. Various types of vehicles (cars and trucks)	No car sharing concept	Car sharing available but no one criterion fulfilled	1 criteria fulfilled	2-3 criteria fulfilled	4 or more criteria fulfilled

		6	Prioritization for low emission vehicles: 1. Subsidies and tax concessions to encourage the purchase and use of low emission vehicles 2. Permission to enter auto restricted zones 3. No traffic restriction (odd-and-even number limit lines) 4. Parking charge discount	No one criterion fulfilled	1 criteria fulfilled	2 criteria fulfilled	3 criteria fulfilled	All criteria fulfilled
	Public Transport	7	Main form of Mass Rapid Transit (MRT)	No public transport connection	No MRT, only bus connection	LRT/BRT	Metro + LRT/BRT	Metro + LRT/BRT + commuter rail
		8	Connection to the major origins and destinations	No connection, or only bus connection to some of the major origins and destinations	Bus connection to the most of major origins and destinations	Bus connection to all major origins and destinations	MRT connection to the most of major origins and destinations, bus connection to the remaining origins and destinations	MRT connection to all major origins and destinations
		9	Transit station coverage rate	<45% (urban area); <63% (city center area)		45%-50% (urban area); 63%-70% (city center area)		>50% (urban area); >70% (city center area)
		10	Velocity of public transport	R>2.5	2<R≤2.5	1.5<R≤2	1<R≤1.5	R≤1
		11	Average wait time in the highest peak hour	>20mins	11-20mins	6-10mins	3-5mins	<3mins
		12	Emission level of buses	Most vehicles meet the National Discharge Standard of Vehicle Pollutant (Ⅰ Stage)	Most vehicles meet the National Discharge Standard of Vehicle Pollutant (Ⅱ Stage)	Most vehicles meet the National Discharge Standard of Vehicle Pollutant (Ⅲ Stage)	Most vehicles meet the National Discharge Standard of Vehicle Pollutant (Ⅳ Stage)	Most vehicles meet the National Discharge Standard of Vehicle Pollutant (Ⅴ Stage)
		13	Quality of public transport vehicles:	Most of vehicles do not fulfill any	1 criterion fulfilled by most vehicles	2 criteria fulfilled by the most of vehicles	3 criteria fulfilled by the most of vehicles	All criteria fulfilled by the most of

			1. Air-conditions 2. Wide doors 3. Passenger travel information 4. Entertainments (e.g. TV, internet service)	criterion				vehicles
		14	Quality of public transport stations: 1. Canopy 2. Ticket machine 3. Passenger travel information 4. Lighting 5. Barrier-free access 6. Bicycle parking infrastructure 7. Small scale shopping possibility nearby	Most of stations do not fulfill any criterion	1-2 criteria fulfilled for the most of stations	3-4 criteria fulfilled for the most of stations	5-6 criteria fulfilled for the most of stations	All criteria fulfilled for the most of stations
	Non-Motorized Transport	15	Connectivity of footpaths	Area is not complete equipped with foot paths along the streets	Area is nearly complete equipped with foot paths along the streets	Area has footpaths separated from the streets	Short & direct footpaths connect to major facilities	Footpaths link to various grades of highway in surrounding areas
		16	Quality of footpaths	Footpaths are too narrow (<2m), barely usable	Footpaths have usable width (≥ 2m)	Footpaths have usable width (≥ 2m); and separated from motorways; most footpaths are smooth, well-lighted, furnished, greened	Footpaths have sufficient width (large city ≥6m; small and medium-sized cities ≥4m) and separation from motorways	Footpaths have sufficient width (large city ≥6m; small and medium-sized cities ≥4m) and separation from motorways; most footpaths are well-paved, well-lighted, furnished, greened
		17	Connectivity of cycle tracks	Area is not complete equipped with cycle tracks	Area is nearly complete equipped with cycle tracks	Area has cycle tracks separated from the roads	Short & direct cycle tracks connect to major facilities	Cycle tracks link to various grades of highway in

					along the roads			surrounding areas
		18	Quality of cycle tracks	Tracks are too narrow (one-way W<2m; two-way W<2.4m), barely usable	Tracks have usable width (one-way 2m≤W<4m; two-way 2.4m≤W<6m)	Tracks have usable width (one-way 2m≤W<4m; two-way 2.4m≤W<6m); and separated from motorways; most tracks are well-paved, well-lighted, furnished, greened	Tracks have sufficient width (one-way 4m≤W; two-way 6m≤W) and separation from motorways	Tracks have sufficient width (one-way 4m≤W; two-way 6m≤W) and separation from motorways; most tracks are well-paved, well-lighted, furnished, greened
		19	Non-motorized vehicle parking: 1.Sufficient parking space at important public service facilities and PT stops 2.Well-equipped bicycle racks and lighting 3.Good security 4.Clear signage	Most of parks do not fulfill any criteria	1 or more criteria fulfilled by several parks	2 criteria fulfilled by the most of parks	3 criteria fulfilled by the most of parks	All criteria fulfilled by the most of parks
	Freight Transport	20	Main freight transport modes	Road transportation is the only mode		Rail-road or port-road is the main mode		Port-road-rail is the main mode
		21	Prioritization for low emission trucks: 1. Subsidies and tax concessions to encourage the purchase and use of low emission vehicles 2. Permission to enter auto restricted zones 3. No restriction for delivering	No one criterion fulfilled	1 criterion fulfilled	2 criteria fulfilled	3 criteria fulfilled	All criteria fulfilled

			time periods 4. Recharging devices in delivering zones 5. Special delivering zones only for low emission trucks					

Indicators of energy in LCISS

Energy	Energy supply side	1	Main sources of energy supply	Conventional energy supply (power grid, gas network, heating network)		One auxiliary energy source (e.g. waste heat, renewable energy, co-generation, etc.) besides conventional energy system		More than one auxiliary energy sources (e.g. waste heat, renewable energy, co-generation, etc.) besides conventional energy system
		2	Renewable energy production	R<5%	5%≤R<10%	10%≤R<15%	15%≤R<20%	20%≤R
		3	Electricity production by co-generation	R=0		0<R<5%		5%≤R
	Energy demand side	4	Green electricity contract	No green electricity contract				Green electricity contract available
		5	Incentive policy of renewable energy utilization	No clear incentive policy and plan		Incentive policies and plans are being developed		Incentive policies and plans have been implemented
		6	Metered heating rate	R<10% (residential building); R<20% (public building)	10%≤R<15% (residential building); 20%≤R<30% (public building)	15%≤R<20% (residential building); 30%≤R<40% (public building)	20%≤R<25% (residential building); 40%≤R<50% (public building)	25%≤R (residential building); 50%≤R (public building)

Indicators of building in LCISS

Building	New buildings	1	Qualification ratio of building energy efficiency in new	R<95%		95%≤R<100%		R=100%

			buildings					
		2	Proportion of green buildings in new buildings	R<5%	5%≤R<20%	20%≤R<35%	35%≤R<50%	50%≤R
	Existing buildings	3	Qualification ratio of building energy efficiency in existing buildings	R<10%	10%≤R<20%	20%≤R<30%	30%≤R<40%	40%≤R

Indicators of water in LCISS

Water	Water supply	1	Water supply from non-traditional sources	R<5%	5%≤R<10%	10%≤R<15%	15%≤R<20%	20%≤R
		2	Water tariff	Increasing block water tariff system not established, water price is lower than the cost	Increasing block water tariff system not established, water price is higher than the cost	Increasing block water tariff system established, water price is lower than the cost	Increasing block water tariff system established, water price is higher than the cost, charge rate cannot balance the payment	Increasing block water tariff system established, water price is higher than the cost, charge rate achieve low profit breakeven
		3	Leakage rate	14%≤R	12%<R<14%	R=12%	10%<R<12%	R≤10%
		4	Coverage of water-saving appliances	R<76%	76%≤R<84%	84%≤R<92%	92%≤R<100%	R=100%
	Wastewater treatment	5	Treatment rate of wastewater	>10% than the average level	≤10% below the average level	Similar like the average level	≤10% above the average level	>10% above the average level
	Stormwater management	6	Stormwater and wastewater diversion	R<100%				R=100%
		7	Drainage system	Not meet the "Code for Design of Outdoor Wastewater"		Meet the "Code for Design of Outdoor Wastewater"		Above the "Code for Design of Outdoor Wastewater"
		8	Flood protection	Not meet the "Code for Design of Urban Flood Control		Meet the "Code for Design of Urban Flood Control		Above the "Code for Design of Urban Flood Control

				Project"		Project"		Project"

Indicators of municipal solid waste in LCISS

Municipal solid waste	MSW collection & transfer	1	Waste collection rate	R<70%	70%≤R<80	80%≤R<90%	90%≤R<100%	R=100%
		2	Proportion of communities with separate waste collection facilities	R=0		0<R<15%		15%≤R
		3	Emission level of waste transport vehicles	Most vehicles meet the national discharge standard of vehicle pollutant (Ⅰ Stage)	Most vehicles meet the national discharge standard of vehicle pollutant (Ⅱ Stage)	Most vehicles meet the national discharge standard of vehicle pollutant (Ⅲ Stage)	Most vehicles meet the national discharge standard of vehicle pollutant (Ⅳ Stage)	Most vehicles meet the national discharge standard of vehicle pollutant (Ⅴ Stage)
	MSW disposal	4	Landfilling rate	>10% above the average level	≤10% above the average level	Similar like the average level	≤10% below the average level	>10% below the average level
		5	Harmless treatment rate	>5% below the average level	≤5% below the average level	Similar like the average level	≤5% above the average level	>5% above the average level

Appendix 13

Score table of weight assignment of LCISS Scale 1

Comparison matrix of first-class indicators

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Urban design								√										Transport
Transport									√									Energy
Energy											√							Urban design

Comparison matrix of second-class indicators

Urban design

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Site planning										√								Land use
Land use										√								Accessibility
Accessibility						√												Site planning

Transport

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Motorized individual transport											√							Public transport
Public transport								√										Freight transport
Freight transport								√										Motorized individual transport

Comparison matrix of third-class indicators

Site planning

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Original land use type													√					Disaster risk
Disaster risk					√													Original land use type

Score table of weight assignment of LCISS Scale 2

Comparison matrix of first-class indicators

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Urban design											√							Transport
Transport								√										Municipal solid waste
Energy							√											Urban design
Building									√									Urban design
Water									√									Urban design
Municipal solid waste									√									Urban design
Energy									√									Transport
Building										√								Transport
Water									√									Transport
Building										√								Energy
Water										√								Energy
Municipal solid waste										√								Energy
Water								√										Building
Municipal solid waste									√									Building
Water							√											Municipal solid waste

Comparison matrix of second-class indicators

Urban design

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Site planning										√								Land use
Land use								√										Accessibility
Accessibility								√										Green open space
Green open space								√										Site planning
Site planning										√								Accessibility
Land use								√										Green open space

Transport

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Motorized individual transport												√						Public transport
Public transport							√											Non-motorized transport
Non-motorized transport										√								Freight transport
Freight transport								√										Motorized individual transport
Motorized individual transport									√									Non-motorized transport
Public transport							√											Freight transport

Water

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Water supply									√									Wastewater treatment
Wastewater treatment								√										Stormwater management
Stormwater management										√								Water supply

Municipal solid waste

Transit-oriented employment density	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
MSW collection & transfer								√										MSW disposal

Comparison matrix of third-class indicators

Site planning

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Original land use type													√					Disaster risk

Land use

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Mixture of functions										√								Urban development land area per capita
Urban development land area per capita										√								Small-scale block
Small-scale block								√										Mixture of functions

Accessibility

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Regional traffic connection										√								Transit-oriented employment density
Transit-oriented employment density								√										Transit-oriented residential density
Transit-oriented residential density								√										Regional traffic connection

Green open space

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Greenery coverage ratio									√									Coverage ratio of green

																		space service radius

Public transport

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Connection to the major origins and destinations												√						Transit station coverage

Non-motorized transport

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Connectivity of footpaths										√								Connectivity of cycle tracks

Supply-side

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Main sources of energy supply								√										Renewable energy production
Renewable energy production								√										Electricity production by co-generation
Electricity production by co-generation										√								Main sources of energy supply

New buildings

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Qualification ratio of building energy efficiency in new buildings									√									Proportion of green buildings in new buildings

Stormwater management

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Stormwater and								√										Drainage prevention

wastewater diversion																		
Drainage prevention										√								Flood prevention
Flood prevention								√										Stormwater and wastewater diversion

MSW disposal

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Landfilling rate											√							Harmless treatment rate

Score table of weight assignment of LCISS Scale 3

Comparison matrix of first-class indicators

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Urban design										√								Transport
Transport								√										Municipal solid waste
Energy							√											Urban design
Building							√											Urban design
Water							√											Urban design
Municipal solid waste								√										Urban design
Energy								√										Transport
Building										√								Transport
Water									√									Transport
Building											√							Energy
Water										√								Energy
Municipal solid waste										√								Energy
Water									√									Building
Municipal solid waste										√								Building
Municipal solid waste									√									Water

Comparison matrix of second-class indicators

Urban design

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Site planning										√								Land use
Land use								√										Accessibility
Accessibility								√										Green open space
Green open space								√										Site planning
Site planning										√								Accessibility
Land use							√											Green open space

Transport

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Motorized individual transport											√							Public transport
Public transport							√											Non-motorized transport
Non-motorized transport									√									Freight transport
Freight transport									√									Motorized individual transport
Motorized individual transport											√							Non-motorized transport
Public transport							√											Freight transport

Energy

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Supply-side								√										Demand-side

Water

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Water supply									√									Wastewater treatment

Wastewater treatment							√										Stormwater management
Stormwater management										√							Water supply

Municipal solid waste

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
MSW collection & transfer								√										MSW disposal

Comparison matrix of third-class indicators

Land use

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Mixture of functions									√									Urban development land area per capita
Urban development land area per capita											√							Small-scale block
Small-scale block								√										Mixture of functions

Accessibility

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Regional traffic connection											√							Transit-oriented employment density
Transit-oriented employment density								√										Transit-oriented residential density
Transit-oriented residential density								√										Regional traffic connection

Green open space

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Greenery coverage ratio									√									Coverage ratio of green space service radius

Coverage ratio of green space service radius								√									Quality of green open space
Quality of green open space									√								Greenery coverage ratio

Motorized individual transport

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Car park management								√										Recharging devices of E-mobility
Recharging devices of E-mobility									√									Car sharing
Car sharing									√									Prioritization for low emission vehicles
Priorization for low emission vehicles								√										Car park management
Car park management								√										Car sharing
Recharging devices of E-mobility									√									Prioritization for low emission vehicles

Public transport

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Velocity of public transport						√												Average wait-time in the highest peak hour
Average wait-time in the highest peak hour							√											Emission level of buses
Emission level of buses									√									Quality of public transport vehicles
Quality of public transport vehicles									√									Quality of public transport stations
Quality of public transport stations												√						Velocity of public transport
Velocity of public							√											Emission level of buses

transport																		
Average wait-time in the highest peak hour							√											Quality of public transport vehicles
Emission level of buses								√										Quality of public transport stations
Quality of public transport vehicles											√							Velocity of public transport
Quality of public transport stations								√										Average wait-time in the highest peak hour

Non-motorized transport

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Quality of footpaths								√										Quality of cycle tracks
Quality of cycle tracks								√										Non-motorized vehicle parking
Non-motorized vehicle parking										√								Quality of footpaths

Supply-side

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Main sources of energy supply							√											Renewable energy production
Renewable energy production							√											Electricity production by co-generation
Electricity production by co-generation												√						Main sources of energy supply

Demand-side

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Green electricity contract										√								Incentive policy of renewable energy

																		utilization
Incentive policy of renewable energy utilization											√							Metered heating rate
Metered heating rate					√													Green electricity contract

New buildings

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Qualification ratio of building energy efficiency in new buildings									√									Proportion of green buildings in new buildings

Water supply

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Water supply from non-traditional sources							√											Water tariff
Water tariff									√									Leakage rate
Leakage rate													√					Coverage of water-saving appliances
Coverage of water-saving appliances							√											Water supply from non-traditional sources
Water supply from non-traditional sources								√										Leakage rate
Water tariff													√					Coverage of water-saving appliances

Stormwater management

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Stormwater and wastewater diversion								√										Drainage prevention
Drainage prevention										√								Flood prevention

Flood prevention									√									Stormwater and wastewater diversion

MSW collection & transfer

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Waste collection rate										√								Proportion of communities with separate waste collection facilities
Proportion of communities with separate waste collection facilities							√											Emission level of waste transport vehicles
Emission level of waste transport vehicles											√							Waste collection rate

MSW disposal

	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	
Landfilling rate											√							Harmless treatment rate