Low-Carbon City Initiatives in China:
Planning Approaches, Dilemmas and Opportunities

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Licentiate Thesis

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Abstract

In order to reduce greenhouse gas (GHG) emissions, tackle climate change and move toward sustainable development, the central government in China has proposed low-carbon city development as the national strategy and relevant initiatives have been taken by local governments. This thesis analyses current low-carbon city programmes and planning approaches in China, identifies limitations and proposes a metabolic approach that could be used to account for physical resources, monitor GHG emissions and involve stakeholders in the planning process.

There are currently two parallel programmes for low-carbon initiatives in China: the “Low-Carbon City” programme and the “Low-Carbon Eco-City” programme. Around thirty cities in the Coastal, Central and Western regions of China have been selected as the national pilot areas for these programmes. This widespread distribution marks a change the previous priority set on development in the Coastal region, meaning that more cities have opportunities to explore low-carbon pathways and obtain support from the state. The large number of cities involved shows China’s determination to transition to low-carbon development in different city contexts. The selected cities have set up local administrative groups to manage low-carbon development and have established integrated approaches to reduce GHG emissions from urban sectors such as energy, transportation, buildings and waste. Some plans have been developed by the cities themselves, while others have involved international cooperation. However, because of limited knowledge on low-carbon city development, an absence of established standards and procedures and the Chinese top-down planning system, low-carbon planning faces specific challenges, such as lack of information about GHG flows, GHG monitoring and stakeholder involvement.

To overcome these challenges and improve low-carbon city approaches in China, this thesis proposes a holistic approach to low-carbon city development, by integrating Industrial Ecology into urban planning. Such work would benefit greatly from adopting a metabolic approach, within which a metabolic approach-based standard is used to understand low-carbon city from GHG flows; a DPSIR framework is used to address root causes of GHG emissions; and an Eco-Cycle Model is used to describe urban metabolism and account for physical resources, monitor GHG emissions and involve stakeholders in the planning process.

The thesis also recommends better collaboration between relevant government departments and stakeholders. Moreover, instead of simply transferring approaches developed elsewhere, international cooperation needs to combine the local context and knowledge in China with international knowledge and experience. In return, experiences from China can help improve low-carbon city approaches in other parts of the world.

Keywords: Low-carbon city; Urban planning; Metabolic approach
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Guanghong Zhou, Stockholm, October 2015
List of Appended Papers

Paper I  

*The author was responsible for i) writing the historical review of concepts and case analysis of Shenzhen; ii) collecting case materials; and iii) revising the related sections according to the feedback from discussions.*

Paper II  

*The author was responsible for i) designing the research; ii) collecting materials regarding low-carbon city concept, low-carbon city programmes in China, Shenzhen case and climate plans in Stockholm; iii) drafting the manuscript with input from co-authors; and iv) revising the paper according to the feedback from discussions and peer reviews.*

Paper III  

*The author was responsible for i) coming up with the research idea in collaboration with co-authors; ii) organising workshops to discuss the DPSIR framework; iii) selecting and analysing low-carbon plans; iv) designing evaluation methods; v) drafting the manuscript with input from co-authors; and vi) revising the paper in collaboration with co-authors according to comments from peer reviewers.*
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<thead>
<tr>
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<th>Full Form</th>
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<tr>
<td>APEC</td>
<td>Asia-Pacific Economic Cooperation</td>
</tr>
<tr>
<td>C40</td>
<td>C40 Cities Climate Leadership Group</td>
</tr>
<tr>
<td>MOHURD</td>
<td>China’s Ministry of Housing and Urban-Rural Development</td>
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<tr>
<td>NDRC</td>
<td>China’s National Development and Reform Commission</td>
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<tr>
<td>DPSIR</td>
<td>Driving forces-Pressures-State-Impacts-Responses</td>
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<tr>
<td>ESMAP</td>
<td>Energy Sector Management Assistance Program</td>
</tr>
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<td>EU</td>
<td>European Union</td>
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<td>GHG</td>
<td>greenhouse gas</td>
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<td>GDP</td>
<td>Gross Domestic Product</td>
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<tr>
<td>IE</td>
<td>Industrial Ecology</td>
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<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
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<td>NGOs</td>
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<td>UK</td>
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<td>UN</td>
<td>United Nations</td>
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<td>UNEP</td>
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<td>UNFPA</td>
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<td>UNSTATS</td>
<td>United Nations Statistics Division</td>
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<td>US</td>
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<td>USEPA</td>
<td>United States Environmental Protection Agency</td>
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<tr>
<td>WCED</td>
<td>World Commission on Environment and Development</td>
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<td>WWF</td>
<td>World Wide Fund for Nature</td>
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1. Introduction

1.1. Background

Tackling climate change, reducing greenhouse gas (GHG) emissions and transitioning to low-carbon city development are becoming increasingly important and urgent components of sustainable development (Swart, Robinson, & Cohen, 2003). One of the most important factors contributing to GHG emissions today is the ongoing rapid urbanisation in the world. Taking China for example, since the Reform and Opening-up Policy was adopted in 1978, there have been three decades of steady economic growth, accompanied by rapid urbanisation. However, this growth has been reliant on vast increases in energy consumption and China is now the world’s largest energy user and the largest GHG emitter (EIA, 2012; EPA, 2013). According to official statistics, 55% (749 million) of the Chinese population lived in cities in 2014 (National Bureau of Statistics of China, 2015). This proportion is predicted to increase to 70%, with 390 million people moving to cities in the next fifteen years (Pan & Wei, 2013). Against this background, if China cannot improve resource use efficiency and reduce emissions, its cities will be unable to adapt to climate change and increased scarcity of resources. Therefore, improving energy efficiency, reducing material consumption and reducing GHG emissions are essential measures for most cities in China.

In the early 1990s, the central government of China started efforts to protect the environment and developed a sustainability strategy, accompanied by policy efforts on GHG emissions reduction (Yuen, 2009). Within this context, low-carbon city development was proposed as a key national strategy in the 11th Five Year Plan (2006-2010). Following that, the 12th Five Year Plan (2011-2015) presented the country’s GHG reduction target for 2015, which was to reduce GHG emissions per unit of Gross Domestic Product (GDP) by 17% from the 2010 baseline (The Central People's Government of the People's Republic of China, 2006, 2011). Moreover, China’s State Council presented a medium-term GHG reduction target for 2020, which aimed to reduce GHG emissions by 40-45% compared with the 2005 baseline (The Central People's Government of the People's Republic of China, 2009). At the local level, by 2012 more than two hundred Chinese municipalities had adopted low-carbon policies from the national level and had taken low-carbon initiatives (CSUS, 2012).

A number of studies have examined low-carbon development in China. Some of these have analysed low-carbon policies (Jiang, Sun, & Liu, 2010; Wang, Liu, Xiao, Liu, & Kao, 2011; Xi et al., 2011; X. Zhang, Shen, Feng, & Wu, 2013) and general programmes (Liu, Liu, & Sun, 2011; Lehmann, 2012). Others (Lo, 2014; Yu, 2014) have evaluated low-carbon city initiatives in term of targets, scope and supporting measures at local level. Although the results of all these studies have provided an overall understanding of low-carbon city concept in China, investigations of planning approaches and discussing advantages, disadvantages and opportunities are limited.
1.2. Aim and objectives

1.2.1. Aim
The overall aim of this thesis was to investigate and analyse current low-carbon city planning approaches in China, explore the possibilities to overcome the limitations these approaches face and improve planning approaches.

1.2.2. Objectives
Specific objectives of the work were:

- To analyse the development of low-carbon city programmes in China.
- To explore planning approaches of low-carbon city initiatives for Chinese cities.
- To investigate challenges of low-carbon urban planning in a Chinese context.
- To assess the potential for an Industrial Ecology approach to improve low-carbon city planning processes in China.

1.3. Research design

1.3.1. Research framework
To analyse the low-carbon city in China, the current situation of sustainable urban development was first investigated and different concepts including the low-carbon city in China were identified. This work was described in *Paper I: Analysis of sustainable urban development approaches in China*. Following that, a deeper analysis was performed on approaches and dilemmas for low-carbon city development in the Chinese context. This work resulted in *Paper II: Towards low-carbon cities in China: Integrating greenhouse gas management in urban planning*. Finally, low-carbon city plans in China were compared with those in cities worldwide. This work resulted in *Paper III: Evaluating low-carbon city initiatives from the DPSIR framework perspective*.

This covering essay thesis is based on the data obtained in Papers I-III. The framework of research is shown in Figure 1.
1.3.2. Brief introduction to Papers I-III

- Paper I: Analysis of sustainable urban development approaches in China

Paper I provided an overview of sustainable urban development approaches in China. It identified the progress of different approaches and analyses their characteristics. To summarise, the national government in China recognised the serious environmental challenges and started initiatives since 1990s. Several concepts such as Green City, Garden City and National Environmental Protection Model City were used in those years, mostly focusing on dealing with environmental issues. Since 2000, the national government has reinforced the strategy of sustainable development and proposed more comprehensive approaches of Eco-City, Low-Carbon City and Low-Carbon Eco-City. Paper I compared three recent concepts using three cases: Tangshan Bay Eco-City, Baoding Low-Carbon City and Shenzhen Low-Carbon Eco-City. For each case, the background and objectives were analysed in detail. Besides, lessons and experiences from Sino-Singapore Tianjin Eco-City, Dongtai Eco-City, Mentougou Eco-Valley, Rizhao and Wuxi were introduced in the paper.

The conclusion reached in Paper I was that the common barriers in China toward sustainable urban development are the lack of clear visions, targets and indicators for these concepts.
Therefore, a DPSIR (Driving forces-Pressures-State-Impacts-Responses) framework was suggested for analysing the dynamics of urban systems, combined with an approach based on an Eco-Cycle Model of metabolic thinking in the urban area. The holistic method could help urban planners to develop resource-efficient pathways and monitor implementation.

- Paper II: Towards low-carbon cities in China: integrating greenhouse gas management in urban planning

Paper II analysed low-carbon city development in the Chinese context. Following the national strategy, hundreds of local governments in China subsequently issued plans toward a low-carbon future. Paper II investigated two low-carbon programmes, Low-Carbon City and Low-Carbon Eco-City, with their approaches and shortages. To summarise, the current low-carbon projects in national pilot schemes have a wide spatial distribution. It provides wide experiences of low-carbon city development for cities with different backgrounds in terms of their economy, geography, history and environment. In addition, Paper II identified some shortcomings of the current low-carbon city projects, taking cases from Shenzhen Low-Carbon Eco-City programme and Wuxi Low-Carbon Eco-City programme. This case analysis revealed two main shortcomings of current low-carbon city planning in China. These are that: i) low-carbon city planning focuses on spatial arrangements, while ignoring the complexity of GHG metabolism; and ii) planning is an expert-driven process, but lacks broad stakeholder involvement. So far, the Chinese low-carbon city planning lacks an approach to systematically monitor GHG emissions.

To devise an improved approach to low-carbon planning, Paper II analysed the experiences of GHG management in Stockholm, Sweden. The results showed that Stockholm has a clear vision to reach fossil-free status by 2050 and has comprehensive policies and plans for achieving this goal. In particular, the Eco-Cycle Model for Stockholm provides a method to illustrate and account for physical resources from an Industrial Ecology perspective. Paper II summarised the lessons on GHG management from Stockholm that could be learnt by China, such as integrating the metabolic approach into urban planning to accounting GHG emissions, improving the planning process and monitoring GHG emissions by all stakeholders concerned.

- Paper III: Evaluating low-carbon city initiatives from the DPSIR framework perspective

In Paper III, thirty-six low-carbon plans from leadership or pilot cities in the world were analysed by application of the DPSIR framework. The results showed that most low-carbon plans focus on technical responses to reduce the large contribution of GHG emissions from the urban energy, transportation and building sectors. Besides, most plans cover institutional and cognitional responses such as policies and legislation; departmental planning and cooperation; measuring, monitoring and reporting performance; capital investment; community education and outreach; and stakeholder involvement. In general, most United States (US) cities have comprehensive low-carbon plans. Some cities in the European Union (EU) and Asia, such as Melbourne, Amsterdam and Xiamen, place more emphasis on low-carbon technology in their plans.
As Chinese cases, Paper III selected the first batch of eight low-carbon city pilots: Tianjin, Chongqing, Shenzhen, Xiamen, Hangzhou, Nanchang, Guiyang and Baoding, to evaluate their plans. The results revealed advantages and disadvantages of China’s low-carbon city planning. Because urban planning is a top-down decision-making process in China and the Chinese government is sufficiently powerful, there is a strong will among administrations for low-carbon plans. However, the top-down system limits stakeholder involvement in planning and cooperation between government departments at the same level. In addition, most low-carbon city plans developed by Chinese cities lack complete awareness of climate change challenge and some of them have omitted to carry out a GHG inventory.

1.4. Thesis structure

This thesis essay, which compiles and extends the work described in the appended papers, is divided into the following six chapters:

- Chapter 1 provides a brief introduction to the study, presenting the background, aim and objectives and summary of papers.
- Chapter 2 presents the theoretical background, including the related concepts of the low-carbon city, urban planning and Industrial Ecology.
- Chapter 3 introduces the methodology of the study.
- Chapter 4 analyses the results obtained in Papers I-III.
- Chapter 5 discusses the results, presents limitations and makes suggestions for future studies.
- Chapter 6 presents the conclusions of the thesis work.
2. Theoretical background

2.1. Low-carbon city agenda

2.1.1. Sustainability and climate change challenge

The concept of sustainable development was proposed in 1987 with the publication of the World Commission on Environment and Development (WCED) report: *Our Common Future*. The core of this concept is to harmonise the economy, society and environment for coming generations (Brundtland, 1987). In the decades since it was first defined, sustainable development has become widely accepted in the environmental discourse, and there were many definitions and interpretations based on the core of WCED (Mebratu, 1998). The latest definition of sustainable development, which was issued in 2013, takes a systems perspective of the Earth and cites: “development that meets the needs of the present while safeguarding Earth’s life-support system, on which the welfare of current and future generations depends” (Griggs et al., 2013).

To reach sustainable development, the United Nations (UN) set eight *Millennium Development Goals* and brought these forward into actions (UN, 2012). However, there are a number of challenges on the way towards sustainable development. These challenges have been divided and summarised in two main categories (Kates, 2001; Jerneck et al., 2011; Griggs, et al., 2013):

- **Alterations of the earth**: Climate change, biodiversity loss, air pollution, land use change, materials and energy consumption and water scarcity.
- **Social transitions**: Ageing and urbanisation of populations, poverty and hunger, gender inequality, health problems, lack of basic education and lack of global partnership.

Rockström (2009) analysed the challenges to planetary boundaries and concluded that climate change, biodiversity loss and nitrogen cycle impacts are three urgent challenges to sustainability today. Climate change has wide and complex impacts on all countries. Rising temperatures could influence public health; changing rainfall patterns could affect water quality and availability; and extreme weather events could result in infrastructure damage and even threaten lives (UN-Habitat, 2012a).

Climate change is caused by long-term GHG emissions. Cities are recognised as the main drivers of GHG emissions, as they release around 70% of GHG emissions (UN-Habitat, 2011). In addition, according to statistics issued by the United Nations Population Fund (UNFPA), more than half the world’s population now lives in cities (since 2008) and the number is expected to reach almost five billion by 2030 (UNFPA, 2007). This means that in a
long time frame, cities are the main battleground in the fight to tackle the challenge of climate change.

2.1.2. Low-carbon city concept

In 2003, the United Kingdom (UK) government published an Energy White Paper entitled “Our energy future: Creating a low carbon economy” (Department of Trade and Industry, 2003). The report proposed the concept of the low-carbon economy, which was the origin of the low-carbon city. Although the low-carbon city concept is now being widely used to tackle global climate challenges, there is no universally accepted definition for this concept. For example, the Climate Group defined the concept as “cities that decouple economic growth from the use of fossil fuel based resources by shifting society and the economy towards consumption based on renewable energy, energy efficiency and green transportation” (Stephens, 2010). The definition by Asia-Pacific Economic Cooperation (APEC) is “towns, cities and villages which seek to become low carbon with a quantitative CO₂ emissions reduction target and a concrete low carbon developing plan irrespective of its size, characteristics and type of development” (APEC, 2011).

Since countries and cities differ from each other, the definition of low-carbon city needs to be made locally, based on the specific situation of e.g. economy, population and energy consumption (Price et al., 2013). However, studies (Li et al., 2012; Chen & Zhu, 2013; Qin & Han, 2013) summarised the characteristics of the low-carbon city in general as:

- Aiming to reduce GHG emissions in the short term and to transition towards a low-carbon society in the long term.
- Applying a life cycle perspective to material flows, improving energy efficiency and reducing GHG emissions.
- Focusing on urban sectors such as building, transportation, waste, industry and energy consumption.

2.1.3. Overview of global low-carbon city initiatives

Climate change was seen as one of the key challenges to sustainability for the Earth Summit in 1992, and climate change policy has now become a key item on the international agenda (Cohen, Demeritt, Robinson, & Rothman, 1998; Grassl & Metz, 2013). In 2008, the United Nations Environment Programme (UNEP) set The World Environment Day slogan as “Kick the Habit! Towards a Low Carbon Economy”, asking countries, companies and communities to focus on GHG emissions and how to reduce them (UNEP, 2008). Following that, UNEP established “Facilitating a transition towards low-carbon societies” as one of the working programme themes in 2010-2011 (UNEP, 2010). Since then, low-carbon development has become a worldwide action.

International society is also devoted to helping the progress of low-carbon development, especially in developing countries. The World Bank and the Energy Sector Management Assistance Program (ESMAP) support low-carbon development in Brazil, China, India,
Indonesia, Macedonia, Mexico, Nigeria, Poland, South Africa and Vietnam (ESMAP, 2012). The World Wide Fund for Nature (WWF) and the HSBC Climate Partnership are assisting low-carbon programmes in Shanghai, Baoding, Beijing, Hong Kong, London, Mumbai, New York and Toronto (WWF, 2007; The Climate Group, 2011). Furthermore, international non-governmental organisations (NGOs) have published several documents to guide low-carbon city development. These documents provide decision makers and planners with relevant methods and approaches on important sectors from local level to national level, such as energy, transportation, land use, waste, water and their administration and monitoring (Table 1).

<table>
<thead>
<tr>
<th>Name</th>
<th>Content and Scope</th>
<th>Main Sectors</th>
<th>Reference</th>
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<tbody>
<tr>
<td>Planning for climate change: a strategic, values-based approach for urban planners</td>
<td>Provides climate action-based solutions for decision-making processes at the local level for middle-income countries.</td>
<td>Land use; Water management; Infrastructure; Transportation; Economic development; Public health; Disaster risk reduction; Energy; Waste; Funding; Outreach; Stakeholder; Administration; Technology and expertise</td>
<td>(UN-HABITAT, 2014)</td>
</tr>
<tr>
<td>Developing local climate change plans: a guide for cities in developing countries</td>
<td>Provides strategies for tackling climate change impacts at local level for developing countries.</td>
<td>Land-use; Energy; Transportation; Waste; Water; Adaptation to climate change; Funding; Monitoring and evaluation</td>
<td>(UN-HABITAT, 2012b)</td>
</tr>
<tr>
<td>Low carbon city: a guidebook for city planners and practitioners</td>
<td>Provides general approaches for low-carbon development at national level based on the UNEP project “Promoting Low Carbon Transport in India”.</td>
<td>Energy; Transportation; Land use; Industry; Building; Waste; Adaptation to climate change</td>
<td>(UNEP, 2013)</td>
</tr>
<tr>
<td>Global protocol for community-scale greenhouse gas emission inventories</td>
<td>Provides methodologies for calculating and reporting city-wide GHG emissions.</td>
<td>Energy; Industry; Building; Agriculture; Forestry; Transportation; Land use; Waste</td>
<td>(WRI, C40 Cities, &amp; ICLEI, 2014)</td>
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Source: (Zhou et al., 2015)

### 2.2. Urban planning

#### 2.2.1. Urban planning theories toward sustainable development

In general terms, urban planning describes the activities needed to arrange spatial structures, manage resources and organise constructions in order to achieve a specific goal in the future (P. Hall, 2002). As cities are complex, where human settlements are interrelated and interact on the economy, politics, culture, environment and other components, urban planning is a comprehensive approach. Today, urban planning involves knowledge from architecture, geography, economics, social science, ecology, etc. (Peter Hall, 2014).
Some trace the beginning of urban planning to 1898, when the concept of the Garden City was proposed (Peter Hall, 2014). At the beginning, the nature of urban planning was to work as a tool to provide better quality of life in cities and its theories continually developed. According to Taylor (1998) and Hall (2014), there was a change in urban planning from a solely physical plan to a plan also including social and environmental conditions after 1945. As Jacobs (1961) pointed out, the physical plan lacked the consideration of society and rational and comprehensive planning was required. In this context, the principle of design with nature, which involved integrating physical planning into environment conditions, was proposed in 1969 (McHarg, 1995). After the Stockholm Declaration in 1972 and the introduction of the concept of sustainable development in 1987, international society began to be concerned with environmental issues and urban planning theories began to move towards achieving a sustainable future.

The United Nations Framework Convention on Climate Change (UNFCCC), which aims to stabilise GHG concentrations “at a level that would prevent dangerous anthropogenic (human induced) interference with the climate system”, entered into force in 1994. Since then, taking actions to address climate change has become a global topic (Kyoto Protocol, 1997). As cities are recognised as the main emitters of GHG emissions that cause climate change, urban planning has started to explore pathways to address climate change. On one side, planners have recognised the environmental impacts of urbanisation. As a result, e.g. Holder (2006) developed the principles of environmental assessment, trying to evaluate the environmental impacts caused by urban development such as construction process of buildings and infrastructure. Meanwhile, planners have been discussing ways to control urban sprawl and reduce GHG emissions from the layout of cities. The concepts of the compact city and smart growth are the topic of significant debate in this context. The urban form of the compact city has been suggested to reduce GHG emissions by increasing land-use density and public transportation (Jenks & Burgess, 2000; Burton, Jenks, & Williams, 2004). Based on its principles, smart growth has been devised as a sustainable urbanisation pathway (Daniels, 2001). Moreover, Calthorpe (2010) integrated the tool of ecological footprints into urban planning for tracking GHG emissions. Urban planning is becoming more comprehensive and diverse and involves many subjects to adapt to climate change.

2.2.2. Urban planning system in China

Urban planning in China plays a leading role for urbanisation. It aims to support achievement of national economic growth and social development goals by guiding urban construction (Leaf & Hou, 2006; Tang, 2011). In this regard, the urban planning system in China has a hierarchy from the national level to local level (Abramson, 2006; Tang, 2011):

- **National plan**: This is the national development strategy, which always contains a five-year plan for socio-economic development.
- **Regional plans**: These follow the requirements of national plan but focus on specific development instructions in the region, such as arranging infrastructure, deciding urban systems and adjusting industrial structures.
• **Local plans:** According to the *Urban and Rural Planning Law*, there are three types of local plan (The National People's Congress, 2007):

  i. **Master Plan:**
  This provides general guidelines for urban development at municipality level in the long-term (usually twenty years). It is based on national socio-economic development and regional urban systems. The role of a Master Plan is to determine the scale and direction of urban development. It arranges the overall layout of urban space, transportation system, industrial structure, urban infrastructure and sets protection standards for history, culture and ecology.

  ii. **Regulatory Detailed Plan:**
  This provides detailed indicators and specific construction requirements based on the Master Plan to control land use. Its main content usually includes function of land, volume ratio of land, size and height of buildings, building density, green space rate, size of public services, restricted areas and other specific requirements.

  iii. **Construction Detailed Plan:**
  This covers the design of urban constructions, including construction conditions analysis, building design, landscape design, road design and investment analysis.

In contrast to most Western countries, the single-party government system in Socialist China determines this central urban planning system (S. Zhang, Roo, & Lu, 2012). However, there has been a gradual transition in urban planning from a centrally planned economy oriented to a market economy oriented since 1949 (Khakee, 1996; Yeh & Wu, 1999). That means that local governments have somewhat more power to make decisions based on the legislation and national standards. This decentralisation provided local planning with flexible choices of industrial, commercial and infrastructural services. More and more private and foreign investment involved in urban development (Leaf & Hou, 2006).

### 2.3. Industrial Ecology

#### 2.3.1. A brief overview of Industrial Ecology

Industrial Ecology (IE) adopts the knowledge of natural ecosystems within industrial systems. In this perspective, IE focuses on material and energy flows in industrial production for sustainable development (Erkman, 1997; Allenby, 2009). According to Erkman (1997), the key characteristics of IE can be summarised as follows:

- It takes a systematic approach to integrate all the related components in the system and make a comprehensive analysis.
- It considers materials and energy flows in the complex system.
- It highlights the role of technology.

With the ecological metaphor, IE takes tools such as material flow analysis (MFA), substance flow analysis (SFA) and life cycle assessment (LCA) and it changes the linear processes to
the closed-loop cycle (Graedel & Allenby, 2003; Ehrenfeld, 2004). In this regard, waste is recycled as a material or energy in the industrial system to reduce impacts on the environment (Garner & Keoleian, 1995).

The application of IE includes technical, sociological and economic aspects at different levels (Graedel & Allenby, 2003). At the municipal level, IE uses ecosystems to understand the urban patterns. It focuses on the components in the urban system, understanding the dynamics of urban development from socio-economic activities. The metabolic tools are used at local level to analyse human activities in cities and the associated energy, water and material flows in urban areas (Ramaswami et al., 2012).

### 2.3.2. Systems thinking in urban planning

Systems thinking provides a method of understanding the dynamic relationships in the world. It is a holistic approach to solve complicated cases. Studies (Maani & Cavana, 2007; Meadows, 2008) summarised the main characteristics of systems thinking as:

- To focus on the whole system and interdependent parts or functions.
- To understand the dynamic feedback that influences the behaviour in an urban system.

The applications of the systems thinking approach are various, such as business, economics, technology and social problems (Maani & Cavana, 2007). It was first introduced into urban planning in the 1960s, when McLoughlin (1969) attempted to provide a general systems theory and framework for urban and regional planning in his book “Urban and Regional Planning: A Systems Approach”. In general, the systems thinking approach to urban planning focuses on understanding the components in the urban system and their dynamic flows (Marcotullio et al., 2003).

### 2.3.3. Urban metabolism

The urban metabolism concept applies a systems approach to cities, takes the city as a system and reflects the technical and socio-economic processes (C. Kennedy, Cuddihy, & Engel - Yan, 2007). In general, the urban metabolism model discovers inputs and outputs in the urban system from a biological perspective (Wolman, 1965; Newman, 1999; Churkina, 2008; Kellett et al., 2013). For example:

- **Input**: Materials and resources such as energy, water and food.
- **Output**: GHG emissions, products and waste.

There are different methods to analyse the inputs and outputs in the urban system. According to Zhang (2013), these approaches can be summarised into four categories:
• **Ecological approach:** Analysing the causes and links in an urban system, and identifying the components from the environment, society and the economy to simulate urban metabolism.

• **Ecological network analysis:** Understanding flows in an urban system by analysing relationships between different components.

• **Input-output analysis:** Integrating economic elements to account for the quantity of materials and energy consumption in the urban system during a metabolic process.

• **Process analysis:** Applying a life cycle perspective to account for materials and final wastes.

An example of urban metabolism is the Eco-Cycle Model 2.0 from the Stockholm Royal Seaport (SRS) project. The model illustrates energy, water, GHG (material) and their metabolism in the SRS area at different scales (Ranhagen & Frostell, 2014) (Figure 2). In addition, the carbon accounting approach for the SRS area illustrates carbon flows from inputs to outputs at global, regional and local levels (Figure 3).

![Eco-Cycle Model 2.0 for the Stockholm Royal Seaport area.](image)

**Figure 2:** Eco-Cycle Model 2.0 for the Stockholm Royal Seaport area.

Source: (Ranhagen & Frostell, 2014)
2.3.4. The DPSIR framework

The DPSIR framework is a conceptual model for describing the complex interactions between socio-economic and ecological systems (Ness, Anderberg, & Olsson, 2010). D (driving forces) refers to the human activities that affect the environment. P (pressures) describes the environmental stress exerted by the human activities, e.g., GHG emissions. S (state) is the current physical, biological and chemical environmental situation. I (impacts) describes the influences on ecosystem, human health and human built environment due to state change, e.g. climate change. R (responses) describes social responses to the environmental issues. In detail, driving forces are human activities within socio-economic systems, which cause environmental pressures. The pressures change the state of the environment and affect both socio-economic and ecological systems. In order to cope with the environmental state and impacts and to influence drivers and pressures, policy makers take some initiatives as responses in society.

Previous studies (Song & Frostell, 2012; Sinha, 2014) have identified two types of DPSIR framework:
• **State/impact-oriented approach:** Responses focus on evaluating environmental state and their impacts for monitoring environmental performances.

• **Pressure-based, driver-oriented approach:** Responses focus on monitoring pressures exerted by the socio-economic driving forces.

In a DPSIR framework, there is a time delay from driving forces to impacts. That means, it is difficult to recognise driving forces and pressures unless environmental state has changed and have impacts. From a systematic perspective, responding to the root causes directly may be an efficient way of approaching environmental management. Therefore, the pressure-based, driver-oriented approach was adopted to analyse current low-carbon initiatives in this thesis. The pressure-based, driver-oriented approach can help model low-carbon pressures by identifying their root causes within socio-economic systems, which could lead to proactive policies and environmental management strategies such as plans.
3. Methods

To analyse current low-carbon city planning development in China, Papers I-III mainly focused on deskwork based on qualitative research methods, including i) literature analysis of relevant publications, government policies, reports and plans; ii) case analysis to explore low-carbon cities; and iii) content analysis of low-carbon plans.

3.1. Literature analysis

Literature analysis focuses on interpreting and analysing the text in an objective way (McGee, 2001). It requires the researcher to search, categorise and summarise the information regarding the research topic provided in the literature (Berg & Lune, 2004). Two types of literature were analysed in this thesis:

- **Government policies, reports and plans**: Papers I-III analysed national policies related to low-carbon city development, government reports and low-carbon plans at the local level.

3.2. Case analysis

The research used case analysis to investigate the specific situation and limitations of either single or group cases (Table 2). In Paper I, in order to analyse different sustainable urban development approaches in China, Baoding and Shenzhen were chosen to represent the different concepts of Low-Carbon City and Low-Carbon Eco-City. That paper also interpreted the Eco-cycle Model in Hammarby Sjöstad, Stockholm, Sweden. Paper II analysed the limitations of low-carbon planning in the cases of Shezhen and Wuxi, compared with the experience from Stockholm. In Paper III, thirty-six plans from worldwide leadership or pilot low-carbon programmes were selected for evaluation, including twenty-one cities from the C40 Cities Climate Leadership Group (C40), seven cities that had won the European Green Capital award and the first batch of eight low-carbon city pilots in China.
Table 2: Selected Chinese cases for analysing low-carbon city approaches.

<table>
<thead>
<tr>
<th>Paper</th>
<th>Selected Cases</th>
<th>Purpose of case analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper I</td>
<td>Baoding and Shenzhen</td>
<td>To analyse different sustainable urban development approaches of Low-Carbon City and Low-Carbon Eco-City.</td>
</tr>
<tr>
<td>Paper II</td>
<td>Shenzhen and Wuxi</td>
<td>To analyse the limitations of low-carbon planning in China.</td>
</tr>
<tr>
<td>Paper III</td>
<td>The first batch of eight low-carbon city pilots in China</td>
<td>To evaluate low-carbon plans and compare the results with other worldwide plans.</td>
</tr>
<tr>
<td></td>
<td>(Tianjin, Chongqing, Shenzhen, Xiamen, Hangzhou, Nanchang, Guiyang and Baoding)</td>
<td></td>
</tr>
</tbody>
</table>

Source: by author

3.3. Content analysis

Content analysis has been widely used in previous studies to characterise information from urban plans (Norton, 2008; Berke, Spurlock, Hess, & Band, 2013; Fu & Tang, 2013; Ordóñez & Duinker, 2013; Eagles, Coburn, & Swartman, 2014; Lyles, Berke, & Smith, 2014). Therefore Paper III used this method to evaluate the selected low-carbon plans. Evaluation indicators were developed from the DPSIR perspective and used with a scale of 0-2 to score the indicators, where a score of “0” means the indicator is not mentioned in the plan; “1” means the indicator is mentioned in brief; and “2” means the indicator is explained in detail. Three rules were applied when grading the indicators:

- If the indicator was written as a specific approach in a separate section, or if the indicator was explained in detail in several sections, the score awarded was “2”.
- If the indicator was mentioned, but not in detail, the score awarded was “1”.
- If the indicator was not mentioned at all, a score of “0” was awarded.

To emphasise the equity and reliability for evaluation, Paper III gave the same weighted values for each indicator and converted the total scores from absolute values to relative values on a scale of 0-10.
4. Results

4.1. Two programmes of the low-carbon city development in China

As described in Paper I, there are a number of concepts used in practice toward sustainable urban development in China. Among these, there are two similar and widely used concepts regarding low-carbon development: “Low-Carbon City” and “Low-Carbon Eco-City” (Table 3).

Table 3: Key distinctions between “Low-Carbon City” and “Low-Carbon Eco-City”.

<table>
<thead>
<tr>
<th>Concept</th>
<th>Proposed by</th>
<th>National pilots launched year</th>
<th>Department</th>
<th>Aim of pilots</th>
</tr>
</thead>
</table>

Source: by author

4.1.1. Low-Carbon City programme

As discussed in Paper I, the Low-Carbon City programme was launched by WWF in 2007, taking Shanghai and Baoding as the pilots (WWF, 2007). Paper II continued the analysis of this programme’s development, in which China’s National Development and Reform Commission (NDRC) launched the national pilots of the first batch of Low-Carbon Provinces and Low-Carbon Cities in 2010 and the second batch in 2012 (NDRC, 2010, 2012) (Table 4). The aim of these pilot projects was to test low-carbon policies and technologies and provide experiences which can be learnt by other cities in China. Therefore, these projects were given specific main tasks. Firstly, the projects had to take low-carbon development as the city goal. Secondly, their low-carbon planning had to consider local conditions and find a way to increase economic development while reducing GHG emissions. Thirdly, these projects had to improve industrial structure and establish a green economy that takes environmental responsibility in economic growth. Finally, they had to encourage a low-carbon lifestyle among citizens.
4.1.2. Low-Carbon Eco-City programme

Both Paper I and Paper II analysed the concept and practices of the Low-Carbon Eco-City. In general, the Low-Carbon Eco-City concept came from the idea of “eco-civilisation”, which was promoted at the 17th National Congress of the Chinese Communist Party in 2007 and emphasised in the 12th Five Year Plan (2011-2015) (The Central People's Government of the People's Republic of China, 2011). The concept is recognised an extension of the low-carbon city, adding features of harmony between human beings and the natural environment. In 2010, Ministry of Housing and Urban-Rural Development (MOHURD) launched a joint national Low-Carbon Eco-City programme in Shenzhen and Wuxi. In 2013, MOHURD launched joint international Low-Carbon Eco-City programme pilots in collaboration with US in Langfang, Weifang, Rizhao, Hebi, Jiyuan and Hefei (MOHURD, 2013) (Table 5). The aim of these pilot projects was to explore pathways of low-carbon transition and reducing energy consumption, as leadership in low-carbon eco-city development. Their main tasks were highlighting energy saving, ecological conservation, green buildings and urban infrastructure (MOHURD, 2011).

Table 4: Chinese provinces and cities appointed as national Low-Carbon City/Province pilots.

<table>
<thead>
<tr>
<th>Year</th>
<th>National Low-Carbon Pilots</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>Guangdong, Liaoning, Hubei, Shanxi and Yunnan</td>
</tr>
<tr>
<td></td>
<td>Tianjin, Chongqing, Shenzhen, Xiamen, Hangzhou, Nanchang, Guiyang and Baoding</td>
</tr>
<tr>
<td>2012</td>
<td>Hainan</td>
</tr>
<tr>
<td></td>
<td>Beijing, Shanghai, Shijiazhuang, Qinhuangdao, Jincheng, Hulunbeier, Jilin, Daxinganling, Suzhou, Huairan, Zhenjiang, Ningbo, Wenzhou, Chizhou, Nanping, Jingdezhen, Ganzhou, Qingdao, Jiyuan, Wuhan, Guangzhou, Guilin, Guangyuan, Zunyi, Kunming, Yanan, Jinchang and Wulumuqi</td>
</tr>
</tbody>
</table>

Source: (Zhou, Liu, Yin, & Frostell, 2014)

Table 5: Chinese cities appointed as Low-Carbon Eco-City pilots.

<table>
<thead>
<tr>
<th>Year</th>
<th>National Low-Carbon Eco-City Pilots</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>Shenzhen and Wuxi (Total of 2)</td>
</tr>
<tr>
<td>2013</td>
<td>Langfang, Weifang, Rizhao, Hebi, Jiyuan and Hefei (Total of 6) in collaboration with US</td>
</tr>
</tbody>
</table>

Source: (MOHURD, 2013)
4.2. Low-carbon city approaches in a Chinese context

4.2.1. Widespread distribution of low-carbon projects

China was divided into three regions (Western, Central and Coastal) by geographical location when the economic reform programme was introduced in 1978. This classification gave the Coastal region priority in industrial development and state financial support until the late 1990s, which widened the economic development gap between the Coastal and other regions (Friedmann, 2005). Even so, Paper II showed that low-carbon pilot projects are widely distributed across the country (Figure 4). This indicates a change in state policy which supports the rest of China for low-carbon transition. From a local perspective, this wide spatial distribution of low-carbon projects gives cities from Western and Central regions financial and technological support, providing them with opportunities to optimise industrial structure and improve infrastructure system and helping them to protect environmental systems during socio-economic development. From a national perspective, since cities differ in terms of economic, geographical, historical and other local conditions, the pathways toward low-carbon cities may be very different. In this regard, having a wide spatial distribution of low-carbon projects can help the government explore different pathways for a low-carbon future and gather experiences in practice.

![Figure 4: Spatial distribution of Low-Carbon City projects in China.](source: modified from (Zhou, et al., 2014))

Note:
National Low-Carbon City (35): Tianjin, Chongqing, Xiamen, Hangzhou, Nanchang, Guiyang, Baoding, Beijing, Shanghai, Shijiazhuang, Qinhuangdao, Jincheng, Hulunbeier, Jilin, Daxinganling, Suzhou, Huai'an, Zhenjiang, Ningbo, Wenzhou, Chizhou, Nanping, Jingdezhen, Ganzhou, Qingdao, Jiyuan, Wuhan, Guangzhou, Guilin, Guangyuan, Zunyi, Kunming, Yanan, Jinchang, Wulumuqi.
National Low-Carbon Eco-City (1): Wuxi
National Low-Carbon Eco-Province (1): Hebei
National Low-Carbon City & National Low-Carbon Eco-City (1): Shenzhen

Source: modified from (Zhou, et al., 2014)
4.2.2. Strong low-carbon city administration

As Paper III discussed, low-carbon city administration in Chinese cities is strong that low-carbon city pilots such as Shenzhen, Wuhan, Chongqing, Tianjin, Nanchang, Hangzhou, Guiyang and Baoding established a joint group respectively, leading directly by their mayors. The joint group makes decisions on low-carbon priorities, such as policies, taxes, markets and finance. This reflects the status of a typical top-down path for low-carbon city development in China.

4.2.3. Low-carbon city plans in the urban planning system

Paper II investigated current low-carbon plans in the urban planning system and identified two types. The first type is an independent plan that is separate from the existing urban planning implementation system, e.g. as in Guiyang. The second type of low-carbon plan is combined in the Master Plan or Detailed Plan, such as in Shenzhen and Wuxi. When it comes to the implementation stage, the first type of low-carbon plan has more limitations, because it is outside the urban planning system and there is no mandatory policy to carry it out. Therefore, in practice, some plans of this type ended up in not being implemented.

Moreover, most of the low-carbon city plans are intended for new urban districts. However, a few cities, such as Shenzhen, are trying to adopt a low-carbon strategy for the whole existing city. Compared with the low-carbon plans for new urban districts, Shenzhen faces more limitations on improving the energy efficiency of buildings and industries in existing built-up areas. This is because of technical difficulties and the higher cost of renovation of old buildings. In addition, this complex situation may result in a long period of reform.

4.2.4. Integrated sector approaches for a low-carbon vision

Paper II selected six cities that belong to the first batch of low-carbon national pilot cities, analysed their low-carbon plans and summarised their approaches. The results showed that these cities have integrated approaches from different sectors (Table 6).
### Table 6: Planning approaches for a low-carbon vision in selected Chinese cities.

<table>
<thead>
<tr>
<th>Low-carbon approach</th>
<th>National Pilot City</th>
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<tbody>
<tr>
<td></td>
<td>Tianjin</td>
<td>X</td>
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<td></td>
<td>Xiamen</td>
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<td></td>
<td>Hangzhou</td>
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<td></td>
<td>Guiyang</td>
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<td></td>
<td>Baoding</td>
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<tr>
<td></td>
<td>Shenzhen</td>
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<tr>
<td>Land use sector</td>
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<td></td>
<td>compact city</td>
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<td></td>
<td>Developing</td>
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<tr>
<td></td>
<td>underground space</td>
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<td>X</td>
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<td>X</td>
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<tr>
<td>Transportation</td>
<td>Developing public</td>
<td></td>
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<td>X</td>
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<td></td>
<td>Encouraging</td>
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<td></td>
<td>non-motorised travel</td>
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<tr>
<td>Household sector</td>
<td>Increasing waste</td>
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<td></td>
<td>recycling</td>
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<tr>
<td>Energy sector</td>
<td>Upgrading</td>
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<td></td>
<td>industries</td>
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<td></td>
<td>Improving energy</td>
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<td>efficiency</td>
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<td></td>
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<td>saving buildings</td>
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<td></td>
<td>Optimising energy</td>
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<td></td>
<td>mix</td>
<td>X</td>
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<td>X</td>
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<tr>
<td>Environment sector</td>
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<td></td>
<td>the carbon sink</td>
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<td>capacity</td>
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<td>Protecting</td>
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<td></td>
<td>environment and</td>
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<td></td>
<td>ecological system</td>
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<tr>
<td>Society sector</td>
<td>Improving</td>
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<td></td>
<td>low-carbon</td>
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<td></td>
<td>technology</td>
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<td></td>
<td>Encouraging</td>
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<td>X</td>
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<td></td>
<td>low-carbon</td>
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<td></td>
<td>lifestyle</td>
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<td></td>
<td>Developing Clean</td>
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<td>Development</td>
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<td></td>
<td>Mechanism</td>
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<td></td>
<td>Setting up GHG</td>
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<tr>
<td></td>
<td>evaluation system</td>
<td>X</td>
<td></td>
<td></td>
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<td>X</td>
</tr>
</tbody>
</table>

Source: (Zhou, et al., 2014)
4.2.5. Close cooperation with the international community

During its exploration of low-carbon development, China’s government kept an open mind to learn knowledge from the international community. As mentioned in Paper I, the low-carbon programme in China was supported by WWF from the beginning, with Shanghai and Baoding being the two cases. Besides, the World Bank has established a long-term relationship with many Chinese cities, such as Tianjin, Beijing, Shanghai and Wuhan, providing support for their low-carbon initiatives (Baeumler, Ijjasz-Vasquez, & Mehndiratta, 2012). Moreover, Paper III highlighted the efforts of China’s government to invite developed countries to join in local low-carbon projects. Countries such as Germany, Sweden and the Netherlands have joint projects in China (de Jong, Yu, Chen, Wang, & Weijnen, 2013).

4.3. Common barriers to China’s low-carbon city planning

4.3.1. Lack of clear understanding of the low-carbon city concept

The lack of knowledge within China of the low-carbon city concept was discussed in Papers I-III. Paper I found that although there are different concepts in China, they are not concretely defined with standards. In practice, this kind of knowledge shortage has resulted in a conventional “spatial plan” for the low-carbon city. Paper II investigated the Low-Carbon Eco-City work plan in Shenzhen. The case analysis showed that the low-carbon plan is still recognised as an extension of the economic development plan. Therefore, although Shenzhen has ambition to change “business as usual”, aiming to reduce GHG emissions but increasing economic growth, the low-carbon plan remains the same. It continues to arrange land use, urban forms and the built environment for socio-economic development, but does not mention the quantitative indicators of energy consumption or GHG emissions.

In addition, Paper III pointed out the background of low-carbon city development in China as a way of transferring the economic development paradigm, shifting the energy consumption based GDP growth for a “green economy” development. Therefore, most of the plans emphasise industrial structure adjustment and clean energy supply in socio-economic activities (Khanna, Fridley, & Hong, 2014). However, planners lack understanding of the nature of the low-carbon city concept when it comes to adapt to climate change. This lack of knowledge has resulted in poor environmental awareness in China, with few cities having proposed approaches for climate change preparedness.

4.3.2. Lack of adequate GHG emissions monitoring in implementation

Paper II pointed out that low-carbon development is a comprehensive issue that requires cooperation from different sectors, such as land use, transportation, energy and waste management. Unfortunately, because of administrative boundaries and the absence of an internal cooperation mechanism, low-carbon planning has not been well integrated into government departments in China (UN-Habitat, 2009). Therefore, the absence of multi-sector coordination between government departments has resulted in little sharing of information on
GHG emissions, which results in insufficient overall GHG emissions monitoring in implementation. According to the results in Paper III, although Chinese cities have proposed targets for reducing GHG emissions, some cities such as Shenzhen, Wuhan, Hangzhou and Baoding lack a GHG inventory in their plans. This lack of GHG inventory data may cause difficulties in monitoring the plan performance of GHG reduction.

### 4.3.3. Lack of stakeholder involvement

Papers I-III all pointed out the limited stakeholder (e.g. local companies and community representatives) involvement in China’s low-carbon city planning. The analysed cases in Paper II and Paper III indicated that the cities of Shenzhen, Wuxi, Tianjin, Nanchang, Hangzhou, Guiyang, Chongqing, Baoding and Xiamen pay little attention to stakeholder involvement. The institutional barrier of urban planning is the main reason for this problem. In China, urban planning is the reflection of government policies and planners’ wishes. To some extent, it is a political process from top to bottom (Leaf & Hou, 2006). Therefore, low-carbon city planning is expertise-oriented, with local policy makers, urban planners and experts in the related sectors invited to formulate the plan. Other stakeholders from society, such as energy companies, transportation companies and community representatives, are less consulted.

### 4.4. Chance to change: A GHG metabolic approach

#### 4.4.1. Understanding a low-carbon city from a GHG flows perspective

The challenges of low-carbon city planning in China, especially spatial arrangement planning, can be summarised as little knowledge of GHG flows. In general, human activities add GHG emissions that influence the terrestrial and oceanic biosphere, causing the global climate change. To understand and account for GHG flows, it is possible to use a global standard proposal Greenhouse Gas Protocol for Chinese cities to report GHG emissions (WRI, et al., 2014). As described in Paper III, this standard is based on a metabolic approach to account for GHG emissions at different scopes. At the municipal level, the proposed three scopes in the standard are widely accepted, according to previous studies by Chavez & Ramaswami (2011) and S. Kennedy & Sgouridis (2011). Scope one is the direct emissions within the city boundary; scope two is the energy-related indirect emissions outside the city boundary; and scope three is other indirect emissions outside the city boundary.

Paper II also emphasised the importance of considering GHG flows at the product level in China. This is because globalisation has transferred product manufacture from developed to developing countries. Therefore, as “the world’s factory”, GHG emissions from production in China are actually connected to consumption in other countries. Understanding GHG flows at the product level can show hidden GHG emissions from material extraction, production, shipping, consumption and waste management of a product. This helps policy makers and planners in China take a broad view of the low-carbon city strategy.
4.4.2. Addressing the low-carbon city at the root causes

To overcome the shortcomings and work toward a low-carbon future in China, Paper I suggested use of the DPSIR framework to describe human activities and environmental effects. Paper III further described these elements in detail in the context of low-carbon development as:

- **Driving forces** indicators, referring to human activities that give the corresponding changes in energy consumption that cause GHG emissions.
- **Pressures** indicators, referring to GHG emissions concentration pressure due to the human activities in the urban area.
- **State** indicators, referring to the status of the environment, such as air quality, water and ecosystem.
- **Impacts** indicators, referring to the environmental influences, such as climate change.
- **Responses** indicators, referring to social responses to the environmental challenges, such as low-carbon policies and plans.

Paper III integrated different types of responses in the low-carbon city context and developed a conceptual framework to help low-carbon city planning (Figure 5). In this framework, specific responses from technical perspective answer the driving forces, pressures, state and impacts, while general responses from institutional and cognitional perspectives give information to support low-carbon city development. The framework can help policy makers and planners take a systems perspective to understand GHG emissions from socio-economic development and their impacts on environment. By identifying root causes of GHG emissions from socio-economic systems, policy makers and planners can measure the environmental pressures, state and impacts, formulate proactive policies and plans to reduce emissions and involve citizens in monitoring the progress. According to the results, most low-carbon plans in China focus little on state, impacts and stakeholder involvement, which has partly hindered the progress of low-carbon city development. Therefore, Paper III argued for coherent approaches in China’s low-carbon city initiatives with the DPSIR framework.
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Figure 5: A conceptual DPSIR (Driving forces-Pressures-State-Impacts-Responses) framework for the low-carbon city.

Source: (Zhou, et al., 2015)
4.4.3. Integrating urban metabolism into GHG accounting and monitoring

Since most urban planners in China come from an architecture background, most low-carbon city plans focus on physical planning, while lacking knowledge of GHG flows. To bridge this knowledge gap, Paper I introduced the Eco-Cycle Model from the Hammarby Sjöstad (HS) project in the 1990s in Stockholm as an example of a metabolic approach (Hammarby Sjöstad, 2010). Paper II went on to introduce the updated Eco-Cycle Model 2.0 and carbon accounting approach, which were mentioned in Section 2.3.3.

Learning from the two versions of the model, Paper I and Paper II discussed a pathway of GHG accounting and monitoring by integrating urban metabolism into low-carbon city planning that could potentially be used in China. Firstly, the Eco-Cycle Model visualises resource flows in the urban system and can be integrated into planning for infrastructure construction in the urban area. Secondly, the quantitative approach to measure carbon emissions reveals the connections between different urban sectors, which could help Chinese urban planners formulate a GHG monitoring indicator system of urban sectors.
5. Discussion

5.1. Low-carbon city planning requires comprehensive knowledge integration

In the process of low-carbon city development, comprehensive knowledge is needed. The Caofeidian project in China, which was carried out in collaboration with Sweden, integrated knowledge of eco-cycles in the urban system and applied technology to waste collection systems and renewable energy (Joss & Molella, 2013). This project demonstrated how to combine ecology knowledge and related technologies in urban planning. However, most urban planners in China lack this kind of knowledge. One important reason is that most urban planning education in China is rooted in architecture or other courses are based on geography and forest science. These training courses in urban planning started in the 1950s. They focus on skills of detailed urban design, while ignoring other types of knowledge for urban development (Zhao & Zhao, 2009). The shortcomings of the education have resulted in current urban plans, such as Master Plans, being based on the conventional approach of deciding the location, layout and other design issues (Khakee, 1996). In low-carbon city development, this will have to change and urban planning will have to integrate knowledge from other disciplines, such as IE, environmental technology, economics, sociology and policy.

5.2. Urban planning system needs improvement towards a low-carbon future

To promote the effectiveness of implementation of a low-carbon plan, it is necessary to add the related content to the legislation system. Taking the Master Plan for example, according to the Urban and Rural Planning Law of 2008, the mandatory content of a Master Plan includes deciding the size of a city, construction area, infrastructure, water system, farmland area, green space area, environmental protection, historical and cultural heritage protection and disaster prevention. Inspired by this, it is suggested that the planning legislation system add mandatory content of low-carbon city plan, such as calculating GHG inventory, improving energy efficiency, providing waste management, protecting ecological system, preparing for climate change impacts, etc.

Moreover, the institutional system of urban planning in China is hierarchical, where the local governments perform tasks and are supervised by a higher level government. The system has been proven to be effective in achieving national economic goals, but lacks coordination between different departments (Khakee, 1996). This shortage has blocked the implementation and monitoring of low-carbon city plans. In addition, in the top-down process of urban planning, stakeholders can contribute little to decision making (S. Zhang, et al., 2012). In reality, however, a low-carbon city is an integrated goal that needs support from the whole
society. It requires a platform to gather different stakeholders and discuss the low-carbon issues. Insufficient stakeholder involvement results in lack of knowledge and public awareness of a low-carbon lifestyle. It also may result in inadequate monitoring of GHG emissions in the implementation phase.

5.3. Learning from both sides during international cooperation

Since the 1920s, China’s urban planners have been exposed to theories and experiences from Western countries. During the Maoist Era in the 1950s, urban planning knowledge came from experts in the Soviet Union. From the 1980s onwards, planning theories and practices from US and Europe have had a significant effect on China’s urban construction (Khakee, 1996; S. Zhang, et al., 2012). As mentioned above, many low-carbon city projects have also been carried out in cooperation with Western countries. This international cooperation has provided worldwide technical assistance and experiences which have improved the planning process in Chinese cities aiming at a low-carbon future. However, since China has unique characteristics compared with the Western world, international best practices need to be combined with local conditions. Meanwhile, lessons learnt in China can be useful to other countries.

The first unique characteristic of China is the size of its population. It is the most populous country in the world, e.g. in 2014 the total population of China was 1367.82 million and the urban population was 749.16 million (National Bureau of Statistics of China, 2015). The low-carbon pilot cities had at least 3 million urban residents in 2013 (Table 7). It has been determined by this large population that instead of “importing” international experiences to China directly, Western knowledge can only be learnt and then adjusted to the local situation. To some extent, this adjustment can help improve the applicability of planning theories and methods (S. Zhang, et al., 2012).

Taking the Eco-Cycle Model as an example, it was developed for Hammarby Sjöstad in Sweden. Tangshan Bay in China, where the planned area is larger and population is more than Hammarby Sjöstad, used the original model as the basis to set up its own waste system and indicators in order to adapt to its local situation (Loftus, 2011; Tangshan Caofeidian Area·Tangshan Bay Eco-city Administrative Committee, 2012). There is also the possibility to test and further develop the model in another context outside Sweden.
### Table 7: Selected cities in China and other countries worldwide from Paper III with low-carbon goals and their urban population in 2013.

<table>
<thead>
<tr>
<th>Country</th>
<th>City</th>
<th>Low-Carbon Goal</th>
<th>Reference</th>
<th>City-proper population*</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>Baoding</td>
<td>Reduce 25% CO₂ intensity below 2005 levels by 2010, and 35% below 2010 levels by 2020.</td>
<td>(City of Baoding, 2008)</td>
<td>10 229 000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(Chongqing Development and Reform Commission, 2010)</td>
<td>29 700 000</td>
</tr>
<tr>
<td></td>
<td>Guiyang</td>
<td>Reduce 40% energy consumption per unit of GDP below 2005 levels by 2020, and reduce 40% CO₂ intensity below 2005 levels by 2020.</td>
<td>(Guiyang Development and Reform Commission, 2010)</td>
<td>4 521 900</td>
</tr>
<tr>
<td></td>
<td>Hangzhou</td>
<td>Reduce 50% CO₂ intensity below 2005 levels by 2020.</td>
<td>(City of Hangzhou, 2009)</td>
<td>8 844 000</td>
</tr>
<tr>
<td></td>
<td>Nanchang</td>
<td>Reduce 38% CO₂ intensity below 2005 levels by 2015, and 45-48% by 2020.</td>
<td>(City of Nanchang, 2011)</td>
<td>5 184 200</td>
</tr>
<tr>
<td></td>
<td>Shenzhen</td>
<td>Reduce 39% CO₂ intensity below 2010 levels by 2015, and 45% below 2005 levels by 2020.</td>
<td>(Shenzhen Development and Reform Commission, 2012)</td>
<td>10 628 900</td>
</tr>
<tr>
<td></td>
<td>Tianjin</td>
<td>Reduce 19% CO₂ intensity below 2010 levels by 2015, and 45% below 2005 levels by 2020.</td>
<td>(City of Tianjin, 2012)</td>
<td>14 722 100</td>
</tr>
<tr>
<td></td>
<td>Xiamen</td>
<td>Reduce 40% energy consumption per unit of GDP below 2005 levels by 2020.</td>
<td>(City of Xiamen, 2010)</td>
<td>3 730 000</td>
</tr>
<tr>
<td>France</td>
<td>Paris</td>
<td>Reduce 30% GHG below 2004 levels by 2020, and 75% by 2050.</td>
<td>(City of Paris, 2007)</td>
<td>2 243 833</td>
</tr>
<tr>
<td>Germany</td>
<td>Berlin</td>
<td>Reduce 85% GHG below 1990 levels by 2050.</td>
<td>(City of Berlin, 2014)</td>
<td>3 375 222</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>Amsterdam</td>
<td>Reduce 40% GHG below 1990 levels by 2025, and 75% by 2040.</td>
<td>(City of Amsterdam, 2009)</td>
<td>779 808</td>
</tr>
<tr>
<td>Norway</td>
<td>Oslo</td>
<td>Reduce 50% GHG below 1991 levels by 2030, and become climate neutral by 2050.</td>
<td>(City of Oslo, 2011)</td>
<td>618 683</td>
</tr>
<tr>
<td>Sweden</td>
<td>Stockholm</td>
<td>Reach fossil fuel-free by 2050.</td>
<td>(City of Stockholm, 2010)</td>
<td>789 024</td>
</tr>
<tr>
<td>United States</td>
<td>Boston</td>
<td>Reduce 25% GHG below 2005 levels by 2020 and 80% by 2050.</td>
<td>(City of Boston, 2014)</td>
<td>636 479</td>
</tr>
<tr>
<td></td>
<td>New York</td>
<td>Reduce 30% GHG below 1990 levels by 2030.</td>
<td>(City of New York, 2011)</td>
<td>8 336 697</td>
</tr>
<tr>
<td></td>
<td>Portland</td>
<td>Reduce 40% GHG below 1990 levels by 2030 and 80% by 2050.</td>
<td>(City of Portland, 2009)</td>
<td>603 106</td>
</tr>
</tbody>
</table>

Compared with Western countries, another unique characteristic is the rapid urbanisation and socio-economic transition in China. Under the Reform and Opening-up Policy, accompanied by the rapid urbanisation, China has also seen a gradual transition from a centrally planned economy to a market economy. This transition has offered some degree of freedom in housing and land markets (Yeh & Wu, 1999). In practice, this influenced the implementation of urban planning, which made the cases different from that in Western countries. The Dongtan project, which was carried out in cooperation with the UK, met the challenges of land use policy and investment (Cheng & Hu, 2010). Although the plan was created with great help from the UK, it failed in implementation.

In addition, the traditional Chinese philosophy, represented by Confucianism, Taoism and Buddhism that has lasted for thousands of years, has impacts on the thoughts and behaviours of Chinese people. In Chinese history, the traditional philosophy advocates a rank order of governments and each social class performs its duties. The idea of government through a top-down administration is the mainstream. The decision making power of citizens is limited and instead people are asked to accept the government’s decisions and actions. The Chinese traditional values are thus different from the Western concepts of civil society, bottom-up decision-making and other social administration values (T. Zhang, 2008; S. Zhang, et al., 2012). These traditional values have shaped the cultural base that influences procedures and institutional roles of urban planning today. Although there is a strong ambition for increased stakeholder involvement in urban planning, it will take time for this transition to occur in China.

5.4. Limitations and future studies

The thesis analysed current low-carbon planning in China and proposed IE-based approaches to help understand the low-carbon concept from a systematic perspective, account for physical resources, monitor GHG emissions and involve stakeholders. Since cities in China all use the same planning system, planners and policy makers in other Chinese cities can use the results in this thesis for reference. However, although the thesis discussed formulating low-carbon plans and institutional systems, it ignored the influence of the market. In fact, in the socio-economic transformation in China today, the market plays an important role in urban development. It also affects the implementation of low-carbon city plans. Therefore, future studies should consider the impacts of market and other factors when analysing the implementation stage of low-carbon plans.

Furthermore, the thesis analysed national pilot low-carbon cities in China, for which the data available was limited. Material on the selected cities mainly came from the literature, while first-hand data from field studies were lacking. To rectify this shortcoming, future studies should choose one of these pilots for further case study. Field studies should be carried out to collect data in the future work. Further methods should also include questionnaire surveys and interviews with different stakeholders.
In addition, cities differ from each other in terms of geographical, economic and cultural background. Therefore, based on the general low-carbon planning principles proposed in the thesis, future studies should focus on comparing specific low-carbon planning approaches in different cities.

Finally, future studies should also investigate the impacts from the international community and compare differences such as their economy, culture and institutional system which influence planning implementation.
6. Conclusions

Climate change is regarded as a challenge to progress towards sustainable development and is a well-established issue on the global agenda. In China, reducing GHG emissions and transitioning to low-carbon cities is the national development strategy. There are two parallel programmes for low-carbon initiatives in China, the “Low-Carbon City” programme and “Low-Carbon Eco-City” programme. The Low-Carbon City programme started in 2007 with WWF and the NDRC later appointed thirty-six national pilots of low-carbon cities and six national pilots of low-carbon provinces. The Low-Carbon Eco-City programme was under the management of MOHURD, which has launched eight national pilots of low-carbon eco-cities.

In general, these national pilot cities and provinces have a wide spatial distribution throughout China’s main regions. This geographical distribution not only gives cities in less developed Western and Central regions the chance to get national policy, finance and technology support, but also provides experiences for low-carbon city development under different socio-economic conditions. Furthermore, low-carbon administration is strong in these projects. The cities involved have established their responsibility groups to guide low-carbon development. As for low-carbon plans, some in these pilot cities involve low-carbon plans in the urban planning system and most refer to new urban areas. In addition, many cities have integrated approaches from different sectors in their low-carbon plans, trying to reduce GHG emissions from energy, transportation, building, waste, etc. Finally, some low-carbon city projects are being carried out in cooperation with international bodies such as WWF and World Bank and countries such as Germany, Sweden and the Netherlands.

However, there are still a number of challenges to China’s low-carbon city planning. At the national level, there is no clear definition and standards regarding the low-carbon city. This has resulted in a lack of planning instructions at local level. Moreover, most urban planners in China have an architecture and geography background, but lack knowledge of low-carbon city requirements and GHG metabolism. In addition, since the urban planning system in China is a top-down process, this limits collaboration between different departments and involvement by stakeholders. Therefore, low-carbon city plans act as “spatial” plans and lack GHG monitoring and stakeholder involvement.

To improve the current low-carbon planning approaches in China, this thesis raises the possibility of integrating a metabolic approach. It suggests introducing this metabolic approach based on an accounting system for GHG flows. Besides, policy makers and urban planners can use the DPSIR framework to analyse the dynamics of GHG flows from a systematic perspective. From the DPSIR framework, low-carbon city plans can address root causes of GHG emissions. The Stockholm Eco-Cycle Model is introduced as a case to show how urban metabolism knowledge potentially work as a pathway to help GHG accounting and monitoring. This model is an application of IE at the city level that illustrates physical resources flows in
the urban system and can be used to account for physical resources, monitor GHG emissions and involve stakeholders in the planning process.

In addition, for a holistic approach to low-carbon city planning in China, there is a need to improve the planning system. In general, urban planning needs to integrate comprehensive knowledge from different aspects, increase collaboration between departments and improve stakeholder involvement. Furthermore, as conditions in China differ from those in Western countries in terms of e.g. population, policy and culture, it is evident that international low-carbon experiences cannot be simply copied for China’s low-carbon city development. In return, experiences from China can contribute to low-carbon city approaches elsewhere in the world.
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