Integrating Low-carbon Concepts in Urban Planning: Practices in Xiamen and Implications

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Abstract: Cities are critical battlefronts in the struggle to mitigate climate change crisis. Urban planning is widely recognized as an important policy and technology tool for the low-carbon development of cities. However, the methods of integrating low-carbon concept into the existing planning system and practices have yet to be studied. More cases are still needed to examine the existing wisdom. By taking the Chinese city of Xiamen as a case study, this study attempts to show a city's efforts to make itself "a low-carbon city in China" in the field of urban planning, to sketch out the general governance framework that make those efforts work, and meanwhile to analyse the problems existing in the process, in the hope of providing some references for those who are concerned about low-carbon city development.

1. INTRODUCTION

Global warming and its related symptoms of climate change have become one of the most pressing issues facing the world. According to the Nobel-Prize-winning Intergovernmental Panel on Climate Change (IPCC), most of the observed increase in average global temperatures since the mid-20th century was likely caused by an increase in anthropogenic greenhouse gas (GHG) concentrations ([IPCC, 2007a](#); [2007b](#)). Therefore, reducing anthropogenic GHG emissions has been widely recognized as an essential countermeasure to mitigate climate change. Lowering the carbon footprints of human activities and reducing carbon emissions, measures that are inherent to the term "low-carbon", are especially critical, because carbon-related CO₂ and CH₄ are two sorts of most important anthropogenic GHGs. These two together account for over 90 percent of global anthropogenic GHG emissions.

Normally, GHG production is described by sector, such as residential and commercial buildings, transportation, industry, or agriculture. "But this division (by sector) obscures a fundamental point: cities are responsible for 80 percent of all GHGs - caused by the way we build and arrange our buildings, by all the stuff we put in them, and by how we move from one building to the next" ([Condon, 2010](#)). This implies that cities are critical battlefronts in the struggle to mitigate climate change. Since the problem is

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caused primarily by cities, cities should therefore be responsible for the solution ([Gurney, et al., 2009](#)).

Although the climate issue is conventionally seen as the province of nation states and international negotiations, the success of climate change action depends on concerted local support ([ICLEI, 1995a; 1995b](#)). The actions taken to reduce GHGs are and will remain to be local efforts in cities ([Agyeman et al., 1998](#)). Studies from a number of countries show that city governments have critical roles in adapting to climate change as well as GHG emission mitigation ([Coenen and Menkveld, 2002; Groven and Aall, 2002; Lindseth, 2004; Climate Group, 2009](#)). Cities exercise key power over many activities that create sources or sinks of GHG emissions, including decisions governing urban form, transportation, energy use, production and distribution, waste and waste-water management, and forest protection ([ICLEI, 1995a; 1995b](#)). Notably, these activities fall within the scope of urban planning. In reshaping urban form and environment, planning tools can be used to influence the energy use of buildings, the amount of travel and modes of transportation, the distribution of carbon sinks, and a host of other decisions that can either advance or hinder climate change mitigation. Low-carbon-oriented planning is therefore a key technology for the development of low-carbon cities ([Gu, et al., 2009](#)).

A number of studies have explored the planning strategies for climate change mitigation. Condon ([2010](#)) summarizes the planning strategies for a post-carbon world as "seven rules": (1) restore the streetcar city; (2) design an interconnected street system; (3) locate commercial services, frequent transit, and schools within a five-minute walk; (4) locate good jobs close to affordable homes; (5) provide a diversity of housing types; (6) create a linked system of natural areas and parks; (7) invest in lighter, greener, cheaper, smarter infrastructures. In *Urbanism in the Age of Climate Change*, Calthorpe ([2011](#)) argues that combining sustainable urbanism – community designs that consider the traditional tenets of urbanism with added emphasis on conservation and regionalism – with renewable energy, conservation techniques, and green technologies offers a solution that can lower carbon emissions, conserve resources, and generate community life. In fact, the main principles of New Urbanism and Smart Growth, which are regarded as "the pioneering reforms before sustainable urbanism" ([Farr, 2008](#)), have already constituted a set of planning strategies to increase resource efficiency and decrease energy demand (thus reducing carbon emissions) in urban areas, including "compact urban form", "mixed land use", "pedestrian-friendly built environment" and "transit-oriented development" ([CNU, 2000](#)).

To a large extent, pioneering studies, including those referenced above, have laid out the principles of sustainable urbanism as well as the design components of "low-carbon planning". However, the methods of integrating these principles and design components into the existing planning system and practices remain to be studied. In general, integrating "low-carbon" concepts into urban planning practices is still in the early stages of an exploratory trial. The planning tools to facilitate low-carbon development have not yet been mastered by city planners and decision makers. Urban planners and local decision-makers need good examples from which to learn and a "learning-by-doing" process to gain a more thorough understanding of low-carbon planning. Besides, integrating low-carbon concepts into urban planning relates to a broader context of urban governance and national strategy in addressing the global challenge of climate change. It is also

important to understand the supportive regulations and policy framework; moreover, the adoption of low-carbon-oriented planning should also fit well within a local development agenda ([Satterthwaite, 2008](#)). In rapidly urbanizing regions (mostly developing countries), the process of urbanization and coping with climate change individually and collectively is an ever-growing challenge to regional and urban planners ([Clark, 2009](#)). On one hand, city planners and decision-makers need to make efforts to accommodate the growing population and economic activities, while cutting down carbon emissions on the other. This is a challenge to city planners and decision-makers, and also a meaningful issue for researchers.

After decades of rapid economic growth, hampered with high-energy consumption and low-efficiency resource utilization, China currently faces some of the most serious energy and environmental problems. Since 2000, China has generated two-thirds of the globally increased carbon emissions ([Garnaut, 2008](#)). In fact, China has recently overtaken the USA as the world's largest CO₂ emitter. China is therefore under great pressure to make developments in energy conservation and GHG emission reduction. Actively cutting carbon emissions to mitigate climate change is not only China's obligation as a responsible major country, but also the only way to achieve sustainable development of the country ([NDRCC, 2007](#); [Xie, 2010](#)). Since China announced its goal of "40-45% reduction of carbon emissions by 2020 based on the 2005 level" at the 2009 Copenhagen Climate Change Conference, pressure has been placed on local authorities at all levels to set and meet their own carbon reduction targets. Actively and effectively reducing carbon emissions without impeding local economic growth is now a central agenda and major concern for all levels of Chinese government. Studying the experiences of low-carbon city development would contribute to the theoretical explorations of both so-called "neo-urbanization" (also known as the "new form of urbanization") and urban planning theory in China ([Dai, 2009](#)). By taking the city of Xiamen as a case study and looking into the field of urban planning, the presented study attempts to show the city's efforts to make itself a low-carbon Chinese city, to draft the general governance framework that makes those efforts work, and to analyze the difficulties and problems existing in the process.

This paper is organized into five sections. Following the introduction, the major challenges to Xiamen's low-carbon development are described in the second section in order to provide a thorough background. In the third section, the strategic framework governing the low-carbon development of Xiamen is illustrated in terms of guiding regulations and higher-level plans, the development objectives, and the deployment of major projects. Next, three low-carbon-oriented planning cases recently conducted in Xiamen are analyzed in details in the fourth section, with a focus on the "low-carbon elements" are integrated into these plans. Finally, in the fifth section, the problems existing in the process and their implications for urban planning are discussed as a conclusion of the paper.

2. MAJOR CHALLENGES TO THE LOW-CARBON DEVELOPMENT OF XIAMEN

2.1 Rapid Economic and Population Growth

The city of Xiamen is located on China's southeast coast (117°53' E - 118°27' E; 24°25'N - 24°55'N). It is one of the earliest four Special Economic Zones (SEZs) in China and a major city on the Taiwan Strait's west bank, with a total administrative area of 1573.16 km². The 131 km² of Xiamen Island is the earliest developed area and remains the central city today.

Like the vast majority of cities in China, Xiamen's economic and social developments have been in a state of rapid growth since the country's reform and opening up. According to the data released by Xiamen's Bureau of Statistics, the city's GDP was only 741 million Yuan in 1981 when the Xiamen Special Economic Zone was newly established. It then surged to 253.6 billion Yuan in 2011, with an average annual growth rate of more than 16%. Notably, the city's GDP crossed the 100 billion Yuan mark in 2006, and the 200 billion Yuan mark in 2010. That means its GDP nearly doubled in just five years. Xiamen City's gross industrial output has continued its growth for many years. The total annual industrial production increased from 111.15 billion Yuan in 2002 to 466.47 billion Yuan in 2012.

At the same time, the population of Xiamen City is also growing rapidly. According to the Sixth National Census data, the resident population of Xiamen City was 353.13 million as of 12am on November 1, 2010. Compared with 205.31 million at the Fifth National Census in 2000, there was an increase of 147.82 million people. This is an increase of 72% over 10 years. The average annual growth rate was 5.57%, significantly higher than Fujian Province's annual average population growth rate of 0.61% during the same period. The rapidly expanding populations brought Xiamen City from the least populated city of the province's nine prefecture-level cities to the fourth largest populated city, after Quanzhou, Fuzhou and Zhangzhou City. In fact, the population growth rate was even far beyond the expectations of Xiamen municipal authorities.

Rapid economic and population growth will inevitably result in an increase of energy demand. Although Xiamen City has been committed to optimizing industrial structure and energy efficiency improvements, and has achieved rather good results (for example, in 2010 Xiamen City's energy consumption per every ten thousand Yuan GDP was 0.569 tons of standard coal, equivalent to 54% of the national average and 71% of the province's average; the industrial added value per ten thousand Yuan was 0.408 tons of standard coal consumption, equivalent to 36% of the province's average). However, the city's total energy consumption still shows continuous growth. As shown in Figure 1, the total energy consumption of Xiamen City in 2004 was 548 million tons of standard coal, increasing to 10.77 million tons of standard coal by 2011. Provided that carbon-based fossil energy structures have not fundamentally changed, this means that urban carbon emissions continued to grow.

Figure 1. Economic growth and energy consumption increase in Xiamen during 2002-2011

2.2 Spatial Sprawl towards a “Bay City”

Since the reform and opening up, cities in China have been experiencing rapid growth and remarkable restructuring. So has the case study city of Xiamen.

The spatial structure of Xiamen city is undergoing a strategic shift and unprecedented change from an "Island City" to a "Bay City". Since the latest revisions of the overall urban planning of Xiamen City (2004-2020) in 2003, Xiamen City has come to the establishment that the development focus would shift from the Xiamen island to outside of Xiamen island. The spatial development strategy is to build Xiamen City into a bay city that has "one heart, two wings, four auxiliaries, eight areas." Among them, "one heart" refers to Xiamen Island with an area of 131 square kilometers (i.e. the Xiamen Island); "two wings" refers to the bays on the east and west sides of the island; the "four auxiliaries" refer to four new towns outside Xiamen Island (auxiliary towns), namely Haicang, Jimei, Tong'an, and Xiang'an; "eight areas" refers to the eight key development areas in the four new towns. Xiamen City has also established the objectives of its comprehensive transportation system planning, which are (1) to service long-term development goals of the bay city, (2) to support Xiamen City's functions as the central city in "Western Taiwan Straits Economic Zone", and (3) to coordinate the city's economic and social development. Under the guidance of this master plan, massive urban development and construction has kicked off in an area several times larger than Xiamen Island; Xiamen City's future traffic patterns expand from the center of the island to new towns outside of Xiamen Island. The demand for motorized transport and its traffic mileage would increase substantially; travel across the sea to and from the island is expected to reach more than 500,000 passengers per day (one-way). With the pace of development in the Western Taiwan Straits Economic Zone, the commute between Xiamen and its east and west wings, Quanzhou and Zhangzhou, will be closer. Guiding and grasping the unprecedented structural adjustments and spatial expansion for Xiamen City is a major issue in front of city policymakers, planners, and researchers.

2.3 Ever-faster Car Boom

While the overall urban form is getting larger and increasingly fragmented, the spatial patterns of people's daily lives have also changed. Working and living are getting separated by housing commercialization (it is

worthy to note that many commercial houses are built in a city's newly developed outskirts) and the disappearance of former "work-unit compound" structures (i.e. welfare housing or factory dormitories). More and more people therefore have to deal with long, frustrating commutes on a daily basis. Meanwhile, urban facilities (such as shops, hospitals, schools, and public transport) are either totally or partly "commercialized", resulting in certain service vacancies where the resident density is not high enough to make those services profitable. Together with the increase in people's income and the inducement of car advertisements, more and more people are choosing to buy a private car when they can afford it ([Wang, 2013](#)). As a result, there has been a surge in automobile purchases in Chinese cities in recent years. In fact, China has become the world's largest automaker and seller since 2009, with two-digit annual growth rates. The yearly sale of cars in China has reached 19.31 million in 2012, once again setting a new world record.

The situation in Xiamen is similar. According to the data released by the Department of Traffic Police, the number of motor vehicles in Xiamen has reached 0.92 million by the end of 2012, of which 0.52 million are private cars (56.14%). The number of newly increased motor vehicles in 2012 was 107226 (8935.5 a month on average). Noticeably, the number of newly increased private cars in 2012 was 92125, accounting for 85.92% of the new vehicles. And the latest data shows that the number of motor vehicles in Xiamen has exceeded 0.95 million in March 2013 (0.54 million cars therein) and is projected to surpass one million in July 2013. Although these numbers seem still modest compared to 94 cars for every 100 people in the USA, the speed at which automobile use is expanding is alarming. The traffic jam has become so serious that the average vehicle speed has fallen to 20 km/h below at peak time, over half of intersections are at the saturated condition, and public parking lots are seriously in shortage. The casualties and economic loss of traffic accident also keep growing, not to mention a series of other negative consequences, such as environment pollution, oil shortage, greenhouse gas emissions, extrusion of public space, access problems for car-less people, and worsening of personal mobility and quality of life. These circumstances not only challenging the city's efforts towards becoming "a role-model of low carbon city" but also damaging its image as "an eco-garden city" and its attractiveness to talents and tourists ([Wang, 2013](#)).

3. STRATEGIC FRAMEWORK GOVERNING THE LOW-CARBON DEVELOPMENT

3.1 Guiding Regulations and Higher-level Plans

Urban planning is an important mechanism for the government to guide urban development. Low-carbon urban planning is supposed to guide the city in the direction of low-carbon development. Low-carbon urban planning cannot be separated from the wider context of urban policies and public governance. It needs a set of supporting policies and regulations.

At the national strategic level, the Chinese government has recognized the resources and environmental pressure, as well as the threats regarding

global climate change. The country has been taking a positive attitude to participate in the actions taken by the international community to cope with climate change. China, as a signatory country to the United Nations Framework Convention on Climate Change and the Kyoto Protocol, actively participated in the preparation and review of previous climate change assessment reports organized by the IPCC, as well as the international negotiations on climate change. Also, based on the requirements of the national strategies for sustainable development established in China's 21st Century Agenda, China has adopted a series of policies and related measures to address climate change.

In 1998, the Chinese government set up the National Climate Change Coordination Group (hereafter referred to as the "the leading group"), under the direct leadership of the State Council, as the national coordinating body to respond to global climate change and energy conservation, the head of which is the National Development and Reform Commission Officer. The main tasks of the leading group are: (1) to study and formulate major strategies, policies and measures related to the national response to global climate change; (2) to unify in the deployment of work on climate change; (3) to consider and study international cooperation and negotiations; (4) to coordinate and solve major problems in the response to climate change; (5) to organize and implement State Council's principles and policies on energy conservation; (6) to unify in the deployment of energy conservation and emission reduction measures; (7) to consider and study major policy proposals; and 8) to coordinate and solve major issues in the work.

As an important obligation to fulfil the United Nations Framework Convention on Climate Change, the Chinese government enacted China's National Climate Change Program in 2007. This program sets out China's position on the issue of climate change, with clearly formulated specific objectives, basic principles, important areas, and its policies and measures in response to climate change. This program is the first national program enacted in a developing country to address climate change. Remarkably, it declares "to include carbon reduction targets as binding targets into the long-term planning of national economic and social development".

As a comprehensive development plan, the National Economic and Social Development Twelfth Five-Year Plan (hereafter referred to as the Twelfth Five-Year Plan), has programmatic descriptions in energy saving, green and low-carbon development, and has established the direction for recent developments. Among the most noteworthy of these developments is that the clearly stated energy consumption per unit of GDP to decrease by 16%, carbon dioxide emissions per unit of GDP to decrease by 17%, and the proportion of non-fossil energy in primary energy consumption to reach 11.4% as a binding development target during the Twelfth Five-Year period. These binding development objectives will eventually be divided into levels and allocated to local governments.

In addition, a series of action plans are organized and implemented at the national level; for example, the program called "low-carbon pilot provinces and cities" has been launched since 2010. Five provinces (Guangdong, Liaoning, Hubei, Shaanxi, and Yunnan), and eight cities (Tianjin, Chongqing, Shenzhen, Xiamen, Hangzhou, Nanchang, Guiyang, and Baoding) were first designated to be pilot provinces or cities.

National strategies for coping with climate change must ultimately be implemented through local actions. The actions of local implementation can be divided into provincial level and city level. For example, as an

undertaking and implementation of national strategies at the provincial level, the Fujian Provincial Government has formulated and promulgated the Action Agenda for the Sustainable Development of Fujian Province and the 12th Five-Year Plan for the Economic and Social Development of Fujian Province. These planned the long-term direction of sustainable development in Fujian Province, arranging the recent framework for actions, clearly defining energy consumption per unit of GDP to decrease by 16%, and CO₂ emissions to decrease by 17.5% as the binding development targets for the 12th Five-Year period. Similarly, the binding targets will be divided and allocated further to various cities in the province.

Xiamen City, as one of the country's first low-carbon pilot cities, has been encouraged by the central government to implement bold innovations in low-carbon development policies and measurements. In 2010, Xiamen City enacted China's first low-carbon urban planning program, the Outline of the Overall Planning for the Low-carbon City of Xiamen, which has not only set a comprehensive framework for the low-carbon actions of Xiamen, but also provided a reference for the other pilot cities across the country.

Figure 2. Framework of national strategies and local implementation plans

3.2 Development Objectives and Target Architecture

As we all know, China announced its goal of "40-45% reduction of carbon emissions by 2020 on 2005 level" at the 2009 Copenhagen Climate Change Conference. China clearly stated that "carbon reduction targets as binding targets will be included in medium-and long-term economic and social development planning, energy consumption per unit of GDP will decrease by 16%, carbon dioxide emissions per unit of GDP will decrease by 17%, the proportion of non-fossil energy in primary energy consumption will reach 11.4%" in the 12th Five-Year period (2011-2015).

Referring to the objectives in the national 12th Five-Year Plan, Fujian Province also put forward its binding development goals stating that energy consumption per unit of GDP will decrease 16%, and carbon dioxide emissions will decrease 17.5% during the 12th Five-Year period.

The city of Xiamen, as one of the earliest national low-carbon pilot cities and the country's renowned eco-garden city, has reached comprehensive low-carbon eco-city development objectives. Table 1 lists the indicators and targets of the Overall Planning for the Low-carbon City of Xiamen. We can see that the development of low-carbon eco-city city of Xiamen includes many different aspects. It focuses on and starts with three major areas of

industrial production, transportation, and building construction, which account for more than 90% of the city's total carbon emissions. Most notably, the energy consumption per GDP in the industrial section is a mandatory target, which echoes the controlling indicators at both the national level and the Fujian Province level. According to this plan, energy consumption per unit of GDP should be maintained below 0.473 tons of standard coal prior to 2015, and should be less than 0.39 tons of standard coal long-term before 2020, amounting to 40% reduction on the 2005 level. The rest of the guiding objectives and targets, although not enforceable, also have a strong indicative significance for the low-carbon development of Xiamen. The indicators and targets also provide guiding criteria for the transformation of urban development models.

Table.1 Target architecture of the development of low-carbon city of Xiamen

Sectors	Approaches	Indicators	Target Value of Indicators			Attribute of Indicators
			Current Value (2010)	Target Value (2015)	Target Value (2020)	
Industry	Industrial Structure Optimization	Proportion of the tertiary industry to GDP	48.9%	$\geq 53.9\%$	$\geq 60\%$	Anticipated
	Total Energy Consumption	Energy consumption per GDP	0.569 tons of standard coal equivalent	< 0.473 tons of standard coal equivalent	≤ 0.39 tons of standard coal equivalent	Mandatory
Land Use	Land-use Efficiency	Added value per industrial land	1.413 billion Yuan / km^2	> 3.5 billion Yuan / km^2	4.5 billion Yuan / km^2	Anticipated
	Land-use Saving	Use of construction land per ten thousand Yuan GDP	11.2 m^2 / ten thousand Yuan	$< 10 \text{ m}^2$ / ten thousand Yuan	$< 7.8 \text{ m}^2$ / ten thousand Yuan	Anticipated
Energy	Energy Structure Reformation	Proportion of renewable energy use	-	$\geq 5\%$	$\geq 20\%$	Anticipated
Building	Green Building	Proportion of the green building accounted for the completed buildings this year (Public building)	-	$\geq 40\%$	$\geq 80\%$	Anticipated
	Building Energy Efficiency	Proportion of energy-efficiency building	32.3%	$\geq 44.2\%$	$\geq 52.6\%$	Anticipated
	Renewable Energy Architecture	Proportion of renewable energy architecture	5%	$\geq 7\%$	$\geq 17\%$	Anticipated
	Building Garbage Disposal	Proportion of building garbage disposal	5%	60%	80%	Anticipated
Transportation	Transit Trip	Share of public transport ridership	about 30%	35% - 40%	$\geq 45\%$	Anticipated

	Transit Network Planning	Average commuting time of the residents in central city	-	≤ 35 minutes	≤ 30 minutes	Anticipated
	Non-motorized Traffic	New-built & rebuilt bicycle lane length (or Chronic channel network density)	-	500 km	1000 km	Anticipated
	New Energy Vehicles	Percentage of new energy vehicles	-	≥ 5%	≥ 15%	Anticipated
Eco-system	Environmental Conservation	Forest coverage	42.8%	42.9%	43.0%	Anticipated
	Coordination of the Urban and Natural Environment	Coverage of urban green area	35.56%	39%	40%	Anticipated
Water Resource & Waste Reuse	Environmental Pollution Control	Proportion of the centralized treatment of waste water	91%	≥ 95%	100%	Anticipated
		Decontamination rate of urban refuse	96.93%	100%	100%	
	Green Infrastructures	Utilization of reclaimed water	0.92%	≥ 10%	≥ 20%	Anticipated
	Water Resources Utilization	Water consumption per GDP	-	< 16 m ³ / ten thousand Yuan	< 8 m ³ / ten thousand Yuan	Anticipated
	Household Waste Disposal	Recycling household waste as resource	16.8%	20%	30%	Anticipated

(Source: *Development of Low-Carbon City of Xiamen (2012)*, Xiamen Construction & Administration Bureau.)

3.3 Major Initiatives and Key Projects

There are many factors at play in climate change mitigation, including alternative energy sources, green technologies that can increase fuel efficiency or reduce energy demand, and new technologies for carbon capture and storage. But these technological measures alone will not be enough. More profound measures involve shifts in the way we build cities and arrange city-regions, and in the way people live their lives. Therefore, the low-carbon city construction is a complicated system engineering with a whole package of countermeasures.

With the general goal of creating natural, economic, and social common development, Xiamen City has taken on a series of initiatives to implement low-carbon urban construction projects. Eleven major low-carbon development projects have been launched for the 12th Five-Year period:

- ◆ Spatial optimization project
- ◆ Low-carbon industrial transformation project
- ◆ Green building propulsion project
- ◆ Clean energy utilization project
- ◆ Low-carbon transportation project

- ♦ Forest carbon sink project
- ♦ Water recycling project
- ♦ Resource recycling project
- ♦ Low-carbon community demonstration project
- ♦ Low-carbon civilization advocacy project
- ♦ Low-carbon financial supporting project

In the field of urban planning and design and of building construction, the following measures have been adopted:

- ♦ Strict implementation of the building energy efficiency standards
- ♦ Energy-saving transformation of major public buildings
- ♦ Renewable energy demonstration projects
- ♦ Green building promotion
- ♦ Adjustment of urban spatial structure plan
- ♦ Promotion of low-carbon neighborhood design
- ♦ Implementation of fully furnished housing
- ♦ Accelerated utilization of underground space

4. LOW-CARBON PLANNING PRACTICES RECENTLY CONDUCTED IN XIAMEN

4.1 Case A: Spatial Governance of Carbon Emissions and Urban Sprawl

For the purpose of guiding low-carbon industrial layout, protecting the eco-environment, and optimizing urban spatial structure, Xiamen City has initiated the Spatial Control Plan for Carbon Emissions. This plan is based on the spatial pattern of the local environment and meant to facilitate socio-economic development. In this plan, the administrative area of Xiamen is divided into several different zones: zones in which carbon emissions will be strictly controlled, zones in which low carbon emissions will be demonstrated, zones in which moderate carbon emissions will be permitted, zero-carbon emission zones, and others (Fig. 3). These carbon emission control policies were implemented at different intensities in different areas. This plan provides a foundation for follow-up on the effects of low-carbon infrastructure, low-carbon industrial layout, and spatial zoning for traffic demand management (TDM).

At the same time, by adjusting the city's master plan, the spatial form of the city can be oriented to a polycentric and cluster-network pattern. Major adjustments include the following: (1) Strengthening the management of the ecological control line and enhancing the ecological buffer zone between different functional areas in order to improve the control of growth boundaries. (2) Improving the internal structure of each urban section by upgrading neighborhood public services and promoting the job-housing balance in order to reduce large-scale, long-distance motorized commuting. (3) Improving public transit between city centers and outside clusters and increasing the volume rate indicators along the major transit corridor in order to promote transit-oriented development (TOD).

4.2 Case B: Regulatory Plan of Xiamen Low-carbon Sci-tech Innovation Park

Currently, there are three large-scale new low-carbon demonstration cities planned in Xiamen. They are the Jimei Low-Carbon Eco-city, the Xiang'an Low-Carbon Industrial Park, and the Xiamen Low-Carbon Sci-tech Innovation Park (hereafter "the Xiamen LCSTP"). This section will focus on the regulatory detailed plan of the Xiamen LCSTP.

The Xiamen LCSTP has a total area of about 4.9 km² and is located at the junction of the Jimei District and the Tongan District in the east bay area of Xiamen. The regulatory detailed planning of Xiamen LCSTP was conducted in 2011. It provides a representative case of integrating a set of low-carbon and eco-city elements into the general framework of urban regulatory detailed planning. Its planning indicator system includes a series of low-carbon-oriented indicators, such as "general energy-saving rate", "green building proportion", "underground space development proportion", "coverage of non-motorized traffic system", "star-grade of green building", "renewable energy utilization rate", "energy consumption quota of per unit building area and so on (see Table 2). The planning targets, specifically green building proportions, coverage of non-motorized traffic systems, and proportion of fully furnished housing are all 100% complete.

Table 2. Planning indicator system for the regulatory plan of Xiamen LCSTP

Approach	Indicator	Unit	Planning Target	Target Attribute
Overall	General energy-saving rate	%	15	Guiding
	Green building proportion	%	100	Suggested
Land Use & Transportation	Underground space development proportion	%	≥ 15	Guiding
	Coverage of non-motorized traffic system	%	100	Mandatory
Water Resource Utilization	Comprehensive runoff coefficient	-	0.46	Guiding
	Unconventional water utilization rate	%	≥ 23	Guiding
Physical Environment	Heat island effect	°C	≤ 1.2 1.5	Guiding
	Wind environment according with criterion	%	≥ 80	Guiding
Energy Utilization	Renewable energy utilization rate	%	5	Guiding
	Energy consumption quota of per unit building area	kWh/(m ² ·a)	25~170	Guiding
Green Building	Star-grade of green building	%	At least national one-star grade	Mandatory
	Proportion of whole-decoration house	%	100	Suggested
	Proportion of native plants	%	70	Suggested

(Source: *Development of Low-Carbon City of Xiamen (2012)*, Xiamen Construction & Administration Bureau.)

4.2.1 Land Use and Transport :

In the frame of China's urban planning system, regulatory detailed planning has become the key of spatial development control. The transport

planning is always a weak link after the regulatory detailed planning was introduced. How to make a land-use plan with thorough consideration of transport system, especially "the green transport system", is a challenge worthy of exploring.

The regulatory detailed planning board of the Xiamen LCSTP has established a transit-oriented land use and spatial development pattern (TOD model) on the basis of ecological sensitivity analyses and traffic models. The idea is to create a sci-tech park with compound functions and a complete green transportation system with the minimum impact on the local environment. The TOD land use model is built upon an upcoming subway line and a bus rapid transit (BRT) line (Fig. 3). The higher-density developments and urban services are arranged around the public transit stations in order to increase the mixed land use and decrease the need for land development near ecologically sensitive areas. The optimization of public transport is also an important goal. The plan emphasizes the connection between internal and external public transport. Within Xiamen LCSTP, the 300-meter coverage of the transit station approaches 70%, and the 500-meter coverage exceeds 90%. The projected ridership of public transport is over 70%. The plan also gives full consideration to pedestrian and bicycle traffic. The non-motorized slow traffic system covers 100% of the road network within the park. This plan incorporates a bicycle lane system and P+R stations to encourage the use of bicycles and new energy vehicles, and areas are reserved for battery charging stations (Figure 4).

Figure 3. Spatial pattern of development density in Xiamen LCSTP under the TOD concept

(Source: *Development of Low-Carbon City of Xiamen (2012)*, Xiamen Construction & Administration Bureau.)

Figure 4. Bicycle corridor and P&R station planning for Xiamen LCSTP

(Source: *Development of Low-Carbon City of Xiamen (2012)*, Xiamen Construction & Administration Bureau.)

4.2.2 Energy Structure:

The regulatory planning of Xiamen LCSTP in particular highlights buildings' energy use, prioritizing renewable energy and efficiency. Solar energy is designated the first-priority renewable energy source, and seawater source heat pumps, surface water source heat pumps and foul water source heat pumps are set as the secondary sources. Renewable energy use is projected to conserve a total of 5824 tons of standard coal, which means it will replace nearly 5% of the buildings' conventional energy use (Figure 5). Residential buildings using renewable energy are planned to conserve a total of 979 tons of standard coal, accounting for 3.32% of the total energy consumption of those buildings. Public buildings that use renewable energy are planned to conserve 4845 tons of standard coal, accounting for 4.02% of its total. In order to ensure effective implementation of renewable energy planning, the plan has set regulatory indicators, specifically renewable energy utilization rates and energy consumption quota per unit building area to strengthen the control and orientation of energy use.

Figure 5. Renewable energy utilization planning for Xiamen LCSTP
(Source: *Development of Low-Carbon City of Xiamen (2012)*, Xiamen Construction & Administration Bureau.)

Figure 6. Allocation of different levels of green building in Xiamen LCSTP
(Source: *Development of Low-Carbon City of Xiamen (2012)*, Xiamen Construction & Administration Bureau.)

4.2.3 Green Buildings:

Green building technology is planned to be fully implemented in the construction of Xiamen LCSTP. All new buildings in the park are required to rate at least one star on the national green building standards. Different green buildings are planned for different areas within the park. One-star green building plots account for 61.20% of the area of the park, two-star green building plots for 10.86%, and three-star green building plots for 3.4% (Figure 6). In addition, the plan also has specific requirements for different types of green buildings (residential or public) from the perspective of energy conservation, land conservation, outdoor environmental impact, and cost.

4.3 Case C: Non-motorized Traffic Promoting Planning in Xiamen

According to the 2050 China Energy and CO₂ Emission Report ([2050 CEACER, 2009](#)), the energy demands of transportation are projected to be grow at an average annual rate of 4% from 2005 to 2050. This means transportation the fastest one among all the energy use sectors in China, and will be the largest contributor to the growth of China's CO₂ emission. Therefore, transportation is a major challenge to mitigating climate change, especially in urban areas where are of the highest concentration of vehicles.

The energy consumption and environmental impact per passenger per kilometer of different types of transportation differ. From least to most, they are as follows: walking → bicycle → rails and subways → buses → taxis → single-occupancy cars. So, to develop an environmental-friendly and low-carbon transport system, a major principle is to promote the non-motorized transport, especially walking and bicycle trip.

As early as 2007, a "Walking for Health" walkway was planned in Xiamen. Research projects on pedestrian and bicycle system planning were also initiated. In 2012, the city of Xiamen was selected by Ministry of Housing and Urban-Rural Development (MOHURD) as a national walking and cycling system demonstration city. As a result, attention and resources are being invested in the improvement of the non-motorized slow traffic systems. Pedestrian and bicycle system promoting plans have recently been promulgated.

4.3.1 Pedestrian System Promoting Planning

The macro-structure of Xiamen City's pedestrian walkway system has been designed according to the city's natural geography patterns and spatial form. The entire city is divided into three planning zones: (1) Green Zone: The mountainous background along the periphery of the urbanized area. It is an important ecological open space, and the walking system within it is relatively independent. It is mainly there for the residents' climbing, leisure, sports, and other routine walking activities. Its main entrances are arranged convenient links with public transport. (2) Orange Zone: The urbanized area. This where the residents spend most of their daily lives. This walking system in this area is the most often used. It is therefore the focus of the most planning. (3) Blue Zone: The long stretches of open beach along the sea. These are the most remarkable areas, reflecting Xiamen's coastal nature. It is available for the residents' seaside exposure, entertainment, leisure, and

other types of walking and jogging activities. The walkway systems were designed to emphasize the continuity along the coastline and the connectivity with the walkway systems in the orange zone.

The city's previous walkway planning paid more attention to leisure and fitness, but paid less attention to the problems of convergence with public transport and public service facilities (Wei, 2008). In the latest round of planning, focusing on the Orange Zone (i.e. the built-up area of the city), a two-tiered walkway system will be improved: (1) Mountain-Sea Walkway Corridors— These are the major walkways linking the hillside area to the seaside area, and each of them ends in a public open space or small park. They are also part of the city's leisure facilities. Through careful redesign of the walking paths, a safe, beautiful, and highly enjoyable public walking space can be created. (2) Walkways Attached to City Roads— These mainly consist of the sidewalks on both sides of the roads throughout the city. They are supposed to facilitate walking from place to place, transfer between different types of transportation, traffic evacuation, and access to public facilities. During planning, particular emphasis has been given to the continuity and accessibility of the entire pedestrian network system (Fig. 7). Very specific design guidelines were established for the construction of walkways, sidewalks, pedestrian bridges, pedestrian underpasses, traffic islands, and maximum distance from transit stations.

At the middle-micro level, the Orange Zone is further divided into 96 pedestrian units. According to the primary function of each unit (such as urban centers, residential areas, and industrial areas), more specific requirements and guidelines are made for the construction of pedestrian systems in each unit.

Figure 7. Pedestrian lanes attached to city roads in Xiamen

(Source: Xiamen City Planning Bureau.)

4.3.2 Public Bicycle System Planning

As an important part of the slow traffic system, bicycle traffic has also received a great deal of attention in Xiamen City. The public bicycle system is a project that the city government has been thinking and operating on in recent years. This is particularly relevant due to the surge automobiles, traffic congestion, and related environmental pollution, which have seriously damaged Xiamen City's image as a renowned "Eco-City", "Garden City", and UN's "Livable City". People's concerns about the surge of car traffic are also increasing. The urge to implement a public bicycle system in Xiamen City has grown increasingly stronger. The NPC deputies and CPPCC members have repeatedly raised related proposals at the People's Congress, and CPPCC meetings in recent years.

In 2012 the Ministry of Housing and Urban-Rural Development of China (MOHURD) selected Xiamen as one of the national pedestrian and cycling system demonstration cities. The construction of public bicycle systems has sped up since then. In the same year, the Xiamen Bureau of City Planning announced the Public Bicycle System Development Planning on Xiamen Island and the Program of Recent Pilot Projects (hereafter "the Xiamen PBS Plan")

According to the Xiamen PBS plan, the city will first build a public bicycle system on Xiamen Island. It will expand the previous leisure-and-tourism-based bike system along the beach lines to a bigger public bicycle system to cover the entire island, which is supposed to function as an additional part of the city's public transport system. To this end, a network of bicycle paths covering Xiamen Island will be built (see Fig. 8). They will include 400 public bicycle rental points, and a supporting smart card (IC or SC) system and a bicycle-tracking GPS system.

The Xiamen PBS Plan indicates that public bike rental service points will be the terminal points of public bicycle trips. These points will also link the public bicycle system with other travel modes. The distribution of rental service points is the key to the entire public bicycle system planning. Based on the functional orientation of the public bicycle system, which will be based on the demand distribution pattern, public bike rental service points will be sorted into residential area points, bus station points, commercial center points, public facility points, tourism and leisure points, etc. Through the planned bicycle lanes, all these points are connected into a network.

According to the Xiamen PBS Plan, the public bicycle project on Xiamen Island will involve a total of 16,000 public bicycles. It is projected to serve some 80,000 passengers a day. If each trip per cyclist is approximately 3 km in length, it will conserve 4800 tons of carbon, assuming that all cyclists would otherwise have taken the bus with a carbon emission rate per passenger per kilometer of 0.160 kg. Assuming that all these cyclists would have ridden in single-passenger cars travel at total of 8800 tons of carbon will be conserved, assuming a fuel consumption per 100 kilometers of 13.29 liters and carbon emissions per liter of fuel of 3.08 kg, saving 2880 tons of fuel per year.

Figure 8. Planned bicycle lane network on Xiamen Island

(Source: [Xiamen City Planning Bureau](#))

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5. DISCUSSIONS AND IMPLICATIONS

In the grand context of the global climate change crisis, after China announced its goal of reducing carbon emissions by 40–45% of 2005 levels by the year 2020, the construction of low-carbon cities became a major goal in urban planning and governance. This also involved the national strategy of seeking breakthroughs in resources and environment bottlenecks to

achieve a transformation of economic growth and sustainable development of the country.

In this work, the author has developed a certain understanding of China's low-carbon urban construction, especially of problems in low-carbon urban planning. Problems observed and the implications for urban planning are summarized below:

- (1) The United Nations Convention on Climate Change (UNFCCC), many countries' national climate change programs, and other authoritative documents tend to fail to address the issue on the basis of urban areas. (It is normally addressed in terms of industrial sectors.) In this way, urban planners and decision-makers in general still lack sufficient knowledge and guidance to address climate change mitigation. For these reasons, deeper, region-specific, comprehensive local studies must be performed and summarized. Relevant international instruments and foreign works should also be introduced to China and disseminated in a timely manner. There is a relatively large body of work abroad, most of them have been published in foreign languages, and it is not easy for most decision-makers and planners in China.
- (2) So far, in China, the studies and professional practices involving low-carbon-oriented urban planning are still preliminary. They are still in a fragmentary, exploratory, learning-by-doing form. Low-carbon urban planning involves specialized knowledge and technology, such as the assessment and analysis of the impact of ongoing climate change on urban areas, regional carbon/oxygen balance analysis technology, and technology suitable for the exploitation of various renewable energy sources. The relevant theories and methodologies are beyond the conventional boundaries of urban planners' knowledge, so planning departments often have to outsource some parts of the job to universities or research institutions. This shows that the conventional education and training systems for urban planners cannot meet the requirements of low-carbon city planning. Urban planners should consciously update their knowledge and institutions of higher education should also adjust and update their course offerings and training programs accordingly.
- (3) Low-carbon-oriented urban planning involves some new planning elements and components. It requires some adjustments to existing planning indicators, such as the proportion of clean energy applications, energy efficiency standards for buildings, the density of land development, the coverage of non-motorized transport networks, reductions in motor vehicle parking spaces and increases bicycle parking spaces and infrastructure, reductions in the number of highways, and increases in the density of minor roads. When adjusting these planning indicators to reflect and realize the low-carbon ideas in planning practices, planners may break the current planning regulations or design codes. For this reason, it is imperative to reform the planning regulatory system and relevant professional norms to meet the demands of low-carbon eco-city planning ([CSUS, 2009](#)). This is currently being explored but has not been completed yet. Thus, some of radical low-carbon plans and designs may not be approved because a number of indicators don't comply with the existing regulations or codes.

- (4) The relevant international conventions addressing climate change request that the effects of the energy conservation and carbon reduction measures be measurable, reportable, and verifiable. This widely recognized principle is also considered to be the key of the Copenhagen Accord ([Winkler, 2008](#)). However, measuring, reporting, and verifying the effects of the energy conservation and carbon reduction measures involved in urban planning is very difficult. So far, there has not yet been any standard working procedure or clear roadmap. Planners often feel powerless and helpless when attempting to measure, report or verify the effects of their proposals. It is due to the insufficiency of relevant fundamental research, also again reveals the limitations of planners' knowledge and experience with respect to climate change mitigation.

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