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China's Development of Low-Carbon Eco-Cities and Associated Indicator Systems

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1. Introduction

China's urban population surpassed its rural population historically in 2011, when the number of Chinese living in towns and cities reached about 690 million[1]. In the years to come, cities in China will face major challenges as their rapidly increasing populations burden already crowded infrastructure systems and exacerbate environmental and climate change issues, threatening public health and quality of life. Low-carbon cities may be key to addressing those challenges, especially as regards mitigating and adapting to climate change. Government entities at both the central and local level have moved aggressively on building low-carbon eco-cities. According to statistics reported by the Chinese Society for Urban Studies, by February of 2011, China will have 230 cities at the prefecture-and-above level that have proposed to establish themselves as “eco-cities,” accounting for 80.1% of the 287 such cities nationally. Of those 230 cities, 133, or 46.3%, have established targets to develop specifically as “low-carbon cities” (Chinese Society for Urban Studies 2011). Given the proposed scale of the effort, China’s potential success or failure in demonstrating and implementing low-carbon eco-cities could greatly affect how the world addresses both the climate change impacts of urbanization and the sustainable development of cities.

Despite the multiple guidelines that have been developed, it remains unclear what defines a low-carbon eco-city. Additionally, although more than 100 indicators have been used or proposed for assessing such cities, few relate directly to energy use or carbon emissions. Nonetheless, policy makers and leaders continue to demand comprehensive toolboxes to facilitate development of low-carbon eco-cities. This paper presents the results of an extensive literature review of the development of low-carbon eco-cities in China. The paper also qualitatively and quantitatively analyzes 11 major indicator systems that researchers, planners, governments, and city managers in China have used to identify low-carbon eco-cities. Finally, the paper gives recommendations for future development, research, and policy design to support low-carbon eco-cities in China and the world.

2. Eco-cities in China: all roads lead to low carbon

Although there is no publicly accepted or officially adopted definition of a low-carbon eco-city, the concept can trace its roots within Chinese customs and culture. China’s traditional cosmological and ecological ideal, which embodies the unity of heaven and humanity, has affected Chinese city design and built environment since ancient times. In modern times, the theory behind low-carbon eco-cities has

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[1] National Bureau of Statistics, The sixth population census communique (No. 1). April 28, 2011. http://www.stats.gov.cn/tjgb/rkpcgb/qgrkpcgb/t20110428_402722232.htm

evolved with, and as a result of, an increasing understanding of ecosystems, sustainable development, carbon footprints, and climate change. The modern theory also interacts and interconnects with commonly used terms from farther back in urban planning and architecture, such as eco-city, sustainable city, garden city, and livable city (see Table 1).

Table 1. Theories Behind Low-Carbon Eco-Cities

Concept or Theory	Background, Definition, and Major Content	Application to Low-Carbon Eco-Cities
Building to unify heaven and humanity	The ancient Chinese believed that humanity, society, and nature form a unified whole, each part similarly constituted and governed by the same laws.	Emphasizes the harmony between the city and surrounding environment.
Sustainable city	This concept calls for integrating into the planning and operation of cities the concept that development by this generation should not sacrifice the development potential of coming generations.	The sustainable city concept is helpful for establishing targets but does not reveal the interconnections between various subsystems.
Garden city	Initiated in 1898 by Sir Ebenezer Howard in the United Kingdom, garden cities were intended to be planned, self-contained communities surrounded by "greenbelts" (parks) and containing proportionate areas of residences, industry, and agriculture.	Supports the building of cities that optimize parks and green spaces.
Livable city	Stresses the quality of life in cities. Standard of living refers to the level of wealth, comfort, material goods, and necessities available to the socioeconomic classes in a city.	Focuses on living standard and the quality of urban development.
Eco-city	Ecological cities (eco-cities) enhance the well-being of citizens and society through integrated urban planning and management, harnessing the benefits of ecological systems while protecting and nurturing them for future generations. Eco-cities strive to function harmoniously with natural systems. They value their own ecological assets, as well as the regional and global ecosystems on which all people depend.	The concept of the eco-city is incorporated directly into the development of low-carbon eco-cities.
Low-carbon city	To address climate change, low-carbon cities decouple economic growth from the use of fossil fuel resources by shifting society and economy toward consumption that relies on renewable energy, energy efficiency, and green transportation.	This concept adds an awareness of carbon emissions and climate change to city development.
Low-carbon eco-city	This concept combines the low-carbon city and eco-city in support of energy-saving and environmentally friendly cities, with an emphasis on low energy consumption, pollution, and carbon emissions.	This concept underlies the theory and practice of a low-carbon eco-city.

Sources: (Wan 2004);(Suzuki, Dastur et al. 2011); (The Climate Group 2010b); (Chinese Society for Urban Studies 2011).

In this section, we first explore the application of the above theories to the emergence and development of eco-cities in China, then review current research and practice by the Chinese government at both the central and local levels.

Cities, which are centers of local and remote environmental impacts, are an appropriate focus for low-carbon development policies. Cities account for an estimated 75% of the world’s energy consumption and 80% of carbon dioxide (CO_2) emissions. China, which has experienced high rates of urbanization, is starting to confront the challenge of climate change. In 2011, China's urbanization rate reached nearly 50%, up from 17.92% in 1978 when the reform period started and China was opened to international trade. Urbanization is projected to reach more than 70% by 2050 (Chinese Society for Urban Studies 2011; Li and Yu 2011). More urban infrastructure and services will be needed to satisfy the demands of future city residents, resulting in higher energy consumption and emissions of greenhouse gases (GHG), including CO_2.

Many in the research community have become interested in the concepts of eco-city, sustainable city, and low-carbon city. Some, for example, have discussed evaluating eco-cities based on alternative indexes such as human development index, social process index, ecological footprint, index for sustainable economic welfare, and material input per service unit (Zhang, Wen et al. 2008). Others have discussed the definition of eco-cities from the perspective of ecological economics, using Yangzhou as a case to explore the use of an indicator system to evaluate the status, progress, and capacity of eco-city development (Wu, Wang et al. 2005). Wenyuan Niu led the Chinese Academy of Science Sustainable Development Strategy Research Group discussed low carbon cities in the background of sustainable development (Liu, Wang et al. 2009). Guiyang Zhuang and others have discussed low-carbon cities in the framework of a low-carbon economy, and have worked with city leaders to demonstrate evaluation and planning theories (Zhuang, Pan et al. 2011). Researchers have focused on the following key issues: the definition and features of an eco-city; the importance of developing eco-cities in China; the indicator system by which to gauge "eco-city-ness"; planning approaches for developing eco-cities, and international best practices (Chinese Society for Urban Studies 2011).

The concept of a *low-carbon eco-city*, a term that combines low-carbon development and eco-city concepts, has been emerging in China since 2008 (Qiu 2009). In 2009, the Chinese Society for Urban Studies released the *Chinese Low Carbon Eco-city Development Strategy*, which discusses techniques and policies to advance low-carbon development in China, including (1) the potential for a low-carbon urbanization strategy, (2) China's regional and urban development strategy based on functional zoning, (3) strategic research for sustainable cities, (4) eco-city planning principles and international best practices, (5) environmental issues and environmental management in China's urbanization process, and (6) China's urban development in the context of the path of sustainable industrial development designated as China's strategy for developing urban public transport (Chinese Society for Urban Studies 2009).

In practice, many organizations and research institutions have partnered with government and other stakeholders to explore the planning and best practices of low-carbon cities in China (The Climate Group 2010a). Beginning in the fall of 2007, the Rockefeller Brothers Fund supported a study in Guangdong and Hong Kong on developing a roadmap to a low-carbon economy for the Pearl River Delta area.[2] In 2008, the World Wildlife Fund (WWF) released a report on its pilot project for a "low-carbon city development

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[2] For more information, see The Climate Group low carbon development project, part of the Grand Pearl River Delta Region Plan. http://www.theclimategroup.org.cn/major_initiatives/policy/pearl_river_delta/.

program," selecting Shanghai and Baoding as pilot cities because of their leadership in attempting to develop such cities.[3] In 2011 WWF published its research on "*Low-Carbon Cities: Why and How*," which detailed the key elements in achieving a low-carbon city[4] (Lei, Zhuang et al. 2011). WWF introduces a tentative model of how to create a low-carbon city, including a comprehensive framework for analyzing a city's emissions inventory; potential low-carbon scenarios; the role of small- and medium-size enterprises; and low-carbon building, transportation, industry, finance, and lifestyle.

There are also some other initiatives work from bottom up approach, for example, the Institute for Sustainable Communities' Low Carbon City Training Program is working with Chinese cities to deepen and scale up successful clean energy models on low-carbon city planning and development[5]. Many other organizations, represented by the Joint US-China Collaboration on Clean Energy (JUCCCE), the Sustainable Development Technology Foundation, the Low Carbon City China Alliance, are developing networks for collaboration on low carbon cities and organizing training programs for shareholders.
Low carbon eco-city also attracts the attention of multi-lateral agencies. In October 2008, the United Nations Development Programme (UNDP), the Government of Norway, and the EU jointly launched a project to support Chinese provincial climate change programs and projects. In April 2010, UNDP released its report titled *China and a Sustainable Future: Towards a Low Carbon Economy and Society*, which stated that a shift to low-carbon development is imperative if China is to sustain its economic development and environment while responding to the challenges of climate change.[6] By the end of 2010, more than 30 provinces, autonomous regions, and municipalities were preparing climate change plans in which cities were identified as key parts of the program (The Climate Group 2010a).

At the level of individual cities, the UK Strategic Programme Fund has supported a development, research, and planning effort to promote low-carbon cities in Jilin City, Nanchang District, Chongqing City, and Guangdong Province.[7] Supported by the Energy Foundation China Sustainable Energy Program, researchers from Tsinghua University and institutions in Suzhou City and Shandong Province have conducted preliminary studies of a low-carbon strategy for Suzhou and Shandong Province.[8] In Guangdong, Hubei, Chongqing, Nanchang, and Baoding, provincial research institutions have been working on low-carbon planning and development. When the Switzerland-China Low Carbon Cities Project was launched in June 2010, eight cities throughout China[9] were selected as pilot cities, based on the criteria of city management, low-carbon economy, transportation, and green building.[10]

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[3] For more information, see the Low Carbon City Initiative in China by World Wildlife Fund (WWF) China. http://www.wwfchina.org/english/sub_loca.php?loca=1&sub=96.

[4] See the full report at WWF China: http://www.wwfchina.org/wwfpress/publication/climate/lowcity_report.pdf (in Chinese).

[5] Institute for Sustainable Communities Low Carbon City Training Program. http://www.iscvt.org/where_we_work/china/

[6] See the full report at UNDP Human Development Reports: http://hdr.undp.org/en/reports/national/asiathepacific/china/nhdr_China_2010_en.pdf

[7] See the full report at Chatham House: http://www.chathamhouse.org/publications/papers/view/109265.

[8] See more about the program introduction at The China Sustainable Energy Program: http://www.efchina.org/FProgram.do?act=list&type=Programs&subType=1.

[9] They are Yinchuan in the Ninxia Autonomous Region, Meishan in Sichuan Province, Dongcheng, the central district of Beijing, Kunming in Yunnan, Baoding in Hebei, Yangling in Shaanxi, and Lushun in Liaoning.

[10] See more about the project at Swiss Agency for Development and Cooperation: http://www.sdc.admin.ch/en/Home/Projects/Low_Carbon_Cities_China.

Further, in its Twelfth Five-Year Plan released in March 2011, China announced that by the end of 2015 it will have reduced energy and carbon intensity by 16% and 17%, respectively, compared to 2010 levels, to meet its target of a 40% to 45% reduction in carbon intensity by 2020 compared to 2005 levels. Those targets are vital to China's national and local efforts to decouple carbon emissions from economic growth. Cities, as loci of energy consumption and carbon emissions, will continue to be at the frontier of China's development of low-carbon eco-cities. Policy makers agree that the focus on carbon emissions related to urbanization is appropriate; the challenge is how to implement the plans and ideals.

3. Government involvement in low-carbon eco-cities

This section discusses the various levels of government involved in developing low-carbon eco-cities in China. Efforts of the central government are described first, followed by a range of local undertakings.

3.1. Central Government Programs

Several entities in China's central government are involved in planning and overseeing efforts to develop eco-cities.

3.1.1. Ministry of Environmental Protection: Eco-City

In pursuit of scientific development[11] and to promote the development of a "resources saving and environmental friendly society," in 2003 China's Ministry of Environmental Protection (MEP) initiated a program to establish eco-counties, eco-cities, and eco-regions nationwide.[12] MEP introduced assessment criteria to evaluate participating entities. MEP revised those criteria in 2005, releasing the revision on December 26, 2007. According to the current criteria, for a city to be considered an eco-city, it must meet the following standards.

The city must (1) establish an "eco-city construction plan" that has been considered, promulgated, and implemented by the Municipal People's Congress; (2) have independent environmental agencies, (3) exceed government-assigned energy savings goals, and (4) receive a score that ranks among the best in the province on an eco-environmental quality index. In addition, 80% of the county (including county-level cities) must attain national ecological construction targets and be named National Environmental Protection Model Cities (Ministry of Environmental Protection 2007).

MEP issued a "*National Ecological County, Ecological City Establishment Assessment (trial)*" on December 13, 2003. In the assessment, the annual average net rural income per capita in developed areas was adjusted from 11,000 to 8,000 yuan (RMB), because the previous version had set it too high.

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[11] The idea of scientific development, sometimes translated as the scientific development perspective, is the current guiding socio-economic ideology of the Chinese Communist Party. The concept incorporates sustainable development, social welfare, a humanistic society, increased democracy, and, ultimately, the creation of a harmonious society.

[12] For more information, see the featured page on the eco-county, eco-city, and eco-region from China's Ministry of Environmental Protection: http://sts.mep.gov.cn/stsfcj/ (in Chinese).

Various indicators in the latest version of MEP's assessment index are discussed in detail in in section 3 of this document.

By July 2011, each of 38 cities, distributed throughout the country, had been named an "Ecological City (County)" under MEP's guidelines and assessment protocol. The cities were in Jiangsu, Shanghai, Zhejiang, Beijing, Shandong, Guanghdong, Sichuan, Anhui, Shaanxi, Tianjin and Liaoning provinces (see Table 2).[13]

3.1.2. Ministry of Housing and Urban-Rural Development: Eco-Garden City

The then Ministry of Construction (MoC) initiated the National Garden City program in 1992. In June 2004, to implement the Strategy of Sustainable Development and lead the eco-environmental development of cities, MoC initiated the Eco-Garden City Program based on the National Garden City program.[14] Qingdao, Yangzhou, Nanjing, Hangzhou, Weihai, Suzhou, Shaoxing, Guilin, Changshu, Kunshan, Jincheng, and Zhangjiagang were among the first demonstration cities. By the end of 2010, the Ministry of Housing and Urban-Rural Development (MoHURD), MoC's successor, had issued 13 releases declaring a total of 184 National Garden Cities designated through the program.[15]

The general requirements for being considered an Eco-Garden City are: (1) developing a comprehensive set of ecological urban development strategies, measures, and action plans; (2) forming a complete urban green space system; (3) prioritizing both the cultural and natural landscapes; (4) improving city infrastructure; (5) providing a good urban living environment; (6) demonstrating that the community actively participates in the policies and measures that formulate and implement the Eco-Garden City; and (7) displaying exemplary implementation of national and local urban planning and ecological and environmental protection laws and regulations.[16]

Any city already designated a National Garden City can apply for the designation of Eco-Garden City, which requires more assessment of the quality of the urban environment. Compared to "garden city" appraisal standards, "eco-garden city" assessments look to such additional factors as quantitative measures of ecological protection, standards for ecological construction and restoration, comprehensive species indexes, the urban heat island effect, the urban ecological environment, and public satisfaction. MoHURD created a basic indicator system for assessing eco-garden cities, which includes 19 primary indicators in three categories: urban ecological environment, urban living environment, and urban infrastructure. The detailed indicators and their assessment standards will be discussed in section 3.

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[13] MEP, National Eco-City (District, County) Name List: http://sts.mep.gov.cn/stsfcj/mdl/201107/t20110722_215314.htm (Released on July 22, 2011; accessed on Sep 18, 2011; in Chinese).

[14] MoHURD, Implementation Opinion on the Establishment of "Eco-garden City": http://www.mohurd.gov.cn/zcfg/jsbwj_0/jsbwjcsjs/200611/t20061101_157113.html (Released on June 15, 2004; accessed on Sep 19, 2011).

[15] A full list of the cities designated "National Garden City" can be found at: http://zh.wikipedia.org/wiki/%E5%9B%BD%E5%AE%B6%E5%9B%AD%E6%9E%97%E5%9F%8E%E5%B8%82 (in Chinese).

[16] See more details on the *National Eco-garden City Standards.* http://www.mohurd.gov.cn/lswj/tz/201012502.doc

3.1.3. National Development and Reform Commission: Low-Carbon City

Being China's central economic coordination body, the National Development and Reform Commission (NDRC) also has primary responsibility for formulating China's climate policy. Following up on the GHG emission target set by the State Council in November 2009 (to lower China's carbon emission intensity by 40% to 45% by 2020 compared to 2005), NDRC is under pressure to explore best practices and international experiences regarding how to battle climate change, reduce carbon emission intensity, and promote green economic development. These goals are to be accomplished while developing the economy and improving people's living conditions during a period of rapid industrial development. Low-carbon city development was therefore proposed in the agenda.

The tasks that low-carbon demonstration cities must pursue include: (1) preparing low-carbon development plans that integrate climate change concerns into the regional Twelfth Five-Year Plan; (2) formulating supporting policies to strengthen the development of green, low-carbon development; (3) accelerating establishment of an industrial system that produces fewer carbon emissions; (4) establishing a system for collecting and managing GHG emission data; (5) promoting low-carbon lifestyles and consumption (National Development and Reform Commission 2010). The first and fourth tasks could be identical, but the other tasks lack clear guidelines.

The official notice from the NDRC announced the selection of Guangdong, Liaoning, Hubei, Shaanxi, and Yunnan provinces and Tianjin, Chongqing, Shenzhen, Xiamen, Hangzhou, Nanchang, Guiyang, and Baoding cities as demonstration provinces and cities. The selections were based on local conditions, current environmental activities, and the potential for low-carbon development in the localities. The assessment details, which might require years to develop, have not been released. Following up on this initiative, more than 40 cities around the country have declared that they are planning to build low-carbon cities, and even more to come. Table 2 lists the cities involved in the various programs overseen by China's central government agencies.

Those programs led by Chinese central governments are independently initiated but are quite similar in their design and implementation. The purposes of those programs are to promote the ministries' respective initiatives on city governance and establish a network of city commitment which means the governance power at ministry level. Those programs lack of coordination in general, though they stress different aspects of the city governance. The MEP Eco-city program stresses the eco-environment of the city, while the MoHURD Eco-Garden City program exams more on the urban development of the city. The eco-environment and the urban development are inseparable but they are under independent assessments by both governmental departments. Those programs extend the hands of central governments and their impact to the city governance, sometimes criticized as to add the burden of the cities. The cities have to deal with different assessments from central governments which have similar function but not always consistent. However, there is also demand from the cities. A few cities have involved all central government programs in order to grad multiple "names" so to fill their anxieties of official performance, besides political or the investment attraction benefits that might come up with the good "name". Therefore, seen from the results, each ministry has a network of cities involved in the program and creates its own community of cities in the names of eco-city, eco-garden city or low carbon city, it would be necessary and helpful to integrate the dispersed directions and move towards consistent efforts.

Table 2. Cities Participating in Central Government Programs

Province	MEP Eco-City	MoHURD Eco-Garden City	NDRC Low-Carbon Demonstration City
Anhui	Huoshan		
Beijing	Miyun, Yanqing		
Chongqing			Chongqing
Fujian			Xiamen
Guangdong	Shenzhen Yantian District, Zhongshan, Shenzhen Futian District, Nanshan District		
Guangxi		Guilin	
Guizhou			Guiyang
Hebei			Baoding
Jiangsu	Zhangjiagang, Changshu, Kunshan, Jiangyin, Taicang, Yixing, Wuxi Binhai, Xishan District, Huishan District, Wujiang, Wuzhou Wuzhong District, Gaochun, Nanjing Jiangning District, Jintan, Changzhou Wujin District, Hai'an	Yangzhou, Nanjing, Suzhou, Zhangjiagang, Kunshan, Changshu	
Jiangxi			Nanchang
Liaoning	Shenyang Dongling District, Shenbei New District		
Shaanxi	Xi'an Saba Ecodistrict		
Shandong	Rongcheng	Qingdao, Weihai	Shenzhen
Shanghai	Minhang District		
Shanxi		Jincheng	
Sichuan	Shuangliu, Chengdu Wenjiang District		
Tianjin	Xiqing District		Tianjin
Zhejiang	Anjie, Yiwu, Lin'an, Tonglu, Pan'an, Kaihua	Hangzhou, Shaoxing	Hangzhou
Cross-program cities	Zhangjiagang, Nanjing, and Kunshan participate in both ithe MEP and MoHURD programs. Hangzhou participates in both the MoHURD and NDRC programs.		

Notes: MoHURD selected 12 Eco-Garden Cities from the 184 National Garden Cites. All statistics were updated in July 2011. Sources: official MEP, MoHURD, and NDRC documents and notices.

3.2. Local Government Programs

This section describes a range sample of programs operated by various local government entities.

3.2.1. Tianjin Eco-City

Tianjin Sino-Singapore Eco-City, a flagship cooperative project between the Chinese and Singapore governments, has the goal of demonstrating the transformation of the current urban development mode in order to tackle climate change, save resources and energy, protect the environment, and achieve social harmony. The development plan targets an area of 30 square kilometers (km^2) having a population of 350,000.

To govern the project, the Chinese government and Singapore established a vice-premier- level joint coordination council and ministerial-level joint working committees in charge of key issues such as urban planning, environmental protection, resource conservation, building a circular economy, practicing ecological construction principles and standards, integrating renewable energy and neutral water-recycling technologies, providing for sustainable development, and promoting social harmony. The Tianjin Eco-City plan, which prioritizes ecological health, also emphasizes community management and public service.

An indicator system comprising 22 controlled indicators and 4 directive indicators[17] was selected as a tool for city planning, development, and construction, with emphasis on eco-environment health, social harmony and progress, economic development, and efficiency. The indicator system stipulates quantitative requirements regarding planning, transportation, ecological restoration, energy supply, community system, water, and so on. Section 3 provides a detailed analysis of the Tianjin indicators.

3.2.2. Caofeidian Eco-City

Caofeidian district is located in Tangshan City, Hebei province. Tangshan, which has an area of 74.3 km^2 and a population of 800,000, is bordered by a deep-water coast that offers good conditions for port development and construction. The Caofeidian eco-city, selected to be developed between the port areas of Jingtang and Caofeidian, has the goal of providing integrated support services for the port, port area, and port city while supporting the expected increase in industrial development and population. Plans call for developing a new eco-city that is “World-Class China Style, and Tangshan Characteristics” despite local challenges such as a severe scarcity of fresh water and saline soil conditions.

Caofeidian eco-city is exploring the following 10 principles to prevent resource destruction, high energy consumption, and environment pollution in the development and urbanization process: a focus on people, resource conservation, green buildings, city security, a recycling economy, green transportation, renewable energy, lifestyle, cultural integration, and highly efficient public utilities. A resource management center is being built to integrate the eco-recycling system and manage the energy, water, and waste systems. The center will be a core resource for guiding the city’s application of new energy, sewage treatment, combined heat and power (CHP), neutral water recycling, and other technologies. The plan for Caofeidian eco-city was constructed through a joint effort of Sweco[18] and the Tsinghua Institute of Urban Planning and Design. The plan focuses on land use and green transportation, water, and green land systems that can integrate resources for constructing a public service center and living service base. A comprehensive indicator system was developed to facilitate the planning and management of the eco-city. The indicator system comprises 141 specific indicators in 7 subcategories: city function, building and building industry, transportation and communication, energy, waste, water, landscape, and public spaces. Chinese experts have stated that utilizing planning tools and detailed indicators in the construction and management process increases the program’s practicality (Chinese Society for Urban Studies 2011).

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[17] A controlled indicator is mandated; a directive indicator is recommended for achieving a given target.

[18] A sustainable engineering and design company headquartered in Stockholm.

3.2.3. Summary of Cities that Plan to Develop Low-Carbon Cities

Following on NDRC's policy push for low-carbon development, many cities have proposed establishing themselves as low-carbon cities, including Zhuhai, Hangzhou, Guiyang, Jilin, Nanchang, Ganzhou, Wuxi, Wanshou, Changping, and Chang-Zhu-Tan (see Table 3). By conducting city-wide low-carbon planning and establishing city-level energy and emissions targets, the cities aim to obtain central government support for developing new policies, projects, and programs. The implementation details of the plans and targets have yet to be fully described, however.

Table 3. Cities Having Low-Carbon Development Targets

City	Low-Carbon Strategy or Target	Relevant Document
Baoding	By 2020 reduce CO_2 intensity by 35% compared to 2010; reduce CO_2 per capita to less than 5.5 tons; make new energy account for 25% of industrial value.	*"Opinion on Constructing Low Carbon City (draft)," 2008;* *"Baoding Low Carbon City Development Plan,"* 2008
Chang-Zhu-Tan	This city is part of a pilot "Resources Saving and Environment Friendly Comprehensive Reform Area."	*Chang-Zhu-Tan City Cluster Regional Plan*, 2009
Chengdu	By 2020, reduce CO_2 intensity by 35% compared to 2010; reduce CO_2 per capita to less than 5.5 tons; make new energy account for 25% of industrial value.	*"Action Plan on Constructing Low Carbon City in Chengdu,"* 2010
Chongqing	By 2015, reduce energy intensity by 16% compared to 2010.	"*Chongqing Low Carbon Transformation Research: Case Study in Chemical, Automobile And Energy Industries,"* 2010
Guiyang	By 2020, reduce energy intensity by 40% and carbon intensity by 45% compared to 2005.	"*Guiyang Low-Carbon Development Action Plan (2010-2020)*" July 2010
Hangzhou	By 2020, reduce carbon intensity by 50% compared to 2005 levels; increase forestry coverage above 68%.	"*Implemented Opinion on the Construction of Low-Carbon City,"* November 2009.
Jilin	Emissions for Jilin City could peak in about 2020 and decline to 60% of the business-as-usual scenario by 2030. Primary energy demand not to exceed 28.18 million and 33.51 million tons of coal equivalents (tce) in 2020 and 2030, respectively.	"*Low Carbon Development Roadmap for Jilin City,"* 2010
Nanchang	By 2015 reduce CO_2 emissions per unit of GDP by 38% compared to 2005 levels; increase the ratio of non-fossil fuels in primary energy consumption to 7%, and increase forest coverage to 25%. By 2020, reduce CO_2 emissions per unit of GDP to 45% -48% of 2005 levels; increase the share of non-fossil fuels in primary energy to 15%; increase forest coverage to 28% and the forest stock to 420 million cubic meters.	"*National Low-carbon City Pilot Nanchang Implementation Plan*" reported to NDRC, October 2010
Shenzhen	Reduce carbon intensity 32% by 2015 and 45% by 2020 compared to 2005. Make non-fossil energy account for 15% of primary energy by 2015.	*"Shenzhen Low Carbon Development Medium and Long-Term Plan (draft),"* April 2011
Tianjin	By 2015, reduce carbon intensity by 15.5% compared to 2010; reduce energy intensity by 15% compared to 2010.	"*Tianjin Climate Change Program,"* March 2010
Wuxi	By 2020, reduce carbon intensity by 45%.	"*Wuxi Low-Carbon City Development Strategic Planning,"* 2010
Xiamen	By 2020, reduce energy intensity by 40% compared to 2005; total carbon emission should peak by 2020.	"*Xiamen Low Carbon Development Master Plan,"* 2010.

Note: Not a complete list. Chongqing, Xiamen, Guiyang, Baoding, Nanchang, Shenzhen, Tianjin, and Hangzhou were selected as low-carbon city demonstration areas. Source: Summarized from government reports and news and adapted from The Climate Group report (2010).

4. Indicator systems and assessment of low-carbon cities

Cities that aim to become low carbon must address two questions: “What is a low-carbon city?” and “How can we assess our attainment of a low-carbon city?” Indicators assessment criteria here can help answer those questions by tracking information both for individual indicators and at a macro level, through the use of aggregated indicators. A macro-level assessment can provide an overall sense of a city’s energy consumption and carbon emissions in order to evaluate to what extent the city is low carbon. Disaggregated sectoral indicators offer detailed information that can provide the foundation for future planning and actions (Zhou, Price et al. 2011). Indicator systems are used widely to define and assess low-carbon cities and thereby help city policy makers identify new directions. Table 4 lists the features of the indicator systems that have been adopted by central government entities and a representative local government, that of Tianjin.

Table 4. Key Features of Selected Indicator Systems

Feature of System	Eco-City(Area)	National Eco- Garden City	Low-Carbon City	Tianjin
Developed by	MEP	MoHURD	NDRC	Tianjin City
Purpose	National assessment of eco-city construction.	Evaluation of National Eco-Garden Cities.	Confronting climate change.	Eco-planning and management of Tianjin eco-city.
Approach	Index system based on a percentile scoring system. Assessment examines the gap between the score and the standard.	Indicator system based on point score. Candidates for National Eco-Garden Cities will be reviewed every 3 years.	Demonstration to explore the feasibility and tools, packages, and policy instruments needed to develop low-carbon cities.	Decomposition of an index system for implementing eco-city planning and construction guidelines.
Basic Condition	Based on "eco-city construction planning," the evaluation index for eco-environmental quality should be among the best in the province.	Planning for a green space system and other basic requirements enables a city to obtain the title of National Garden City.	Local conditions serve as the foundation for low-carbon development; based on representativeness of the demonstration.	N/A
Structure of Indicators	Stratified, with targets and indicators in three components: economy, society, and environment.	Stratified, with targets and indicators in three components: natural environment, living environment, and infrastructure.	N/A	Stratified, with targets, paths, and indicators in four components: economy, society, environment, and regional coordination.
Number of Indicators	22	19	N/A	22
Timeframe	2007	2004	2010	Now, 2013, and 2020

Source: Chinese Society of Urban Studies, 2011. NDRC’s pilot program for low-carbon cities has not yet released any details.

Most indicator systems have three structured layers, a target, a path, and an indicator layer. The target layer provides the overall goal; the path layer creates subcategories (as shown in Table 5) for the indicator system; and the indicator layer lists specific indicators used to evaluate progress in the path and target layers. In Tianjin, for example, low-carbon planning has divided the city into four major target areas: economy, society, environment, and regional coordination. MEP focuses primarily on the environmental aspects, while MoHURD focuses more on the built environment and infrastructure. MoHURD's system has no indicators related to energy, industry, or economy; the MEP system has no indictors for transportation or the thermal environment. No indicator system has been released for NDRC's low-carbon city program.

Table 5. Key Indicators for Major Systems

System	Eco-city (MEP)	Eco-Garden City (MoHURD)	Tianjin
Energy use	(1) energy consumption per unit of GDP	N/A	(1) carbon emissions per unit of GDP; (2) utilization rate for renewable energy
Water use	(2) consumption of fresh water per unit of industrial value added; (3) coefficient of effective utilization of irrigation water; (4) rate of industrial water recycling	(1) utilization of reclaimed water; (2) extent of tap water penetration	(3) per-capita water consumption; (4) utilization of non-conventional water resources
Solid waste	(5) treatment rate for city household waste; (6) utilization of industrial solid waste	(3) decontamination rate of urban refuse	(5) rate of garbage collection; (6) per-capita waste disposal; (7) decontamination rate of hazardous waste and garbage
Water environment	(7) compliance rate for drinking water quality at centralized source; (8) rate of urban sewage treatment ; (9) water quality	(4) compliance rates for functional areas of urban water quality; (5) overall rate for water distribution network; (6) rate of urban sewage treatment	(8) rate of compliance for tap water; (9) local surface water quality; (10) net loss of natural wetlands
Air quality	(10) air quality; (11) intensity of discharge of major pollutants	(7) days of air pollution indices less than or equal to 100	(11) regional air quality
Landscape	(12) forest coverage; (13) proportion of protected areas in total land area; (14) per-capita urban public green area	(8) green coverage; (9) per-capita public green space in built area; (10) percent of green land ; (11) composite index of species; (12) native plant index	(12) native plant index; (13) per-capita public green space
Sonic environment	(15) noise; environmental quality	(13) area ambient noise standard	(14) compliance rate of functional area noise standard
Transportation	N/A	(14) average speed of primary and secondary roads; (15) proportion of permeable road area in built-up area	(15) proportion of green travel
Thermal environment	N/A	(16) urban heat island effect	N/A

Services	(16) level of urbanization; (17) penetration rate of district heating; (18) rate of public satisfaction with the environment	(17) public satisfaction with the urban ecological environment; (18) urban infrastructure systems; (19) number of hospital beds per 10,000 people.	(16) free accessible facilities within 500 meters' walking distance of residential area; (17) number of disabled-access facilities; (18) coverage of municipal pipe network; (19) affordable housing as a proportion of total housing; (20) balance between employment and housing indexes
Industry and economy	(19) per-capita net income of farmers; (20) proportion of tertiary industry in GDP; (21) acceptance rate for compulsory clean production enterprises; (22) proportion of environmental protection investment to GDP	N/A	(21) full-time equivalent workers in R&D, scientists, and engineers per 10,000 persons
Green building	N/A	N/A	(22) percentage of green buildings

Source: Chinese Society of Urban Studies. Adapted from Xia Chunhai, Eco-cities index system comparison research, 2011.

4.1. Indicator Systems Examined

Indicator systems are used widely by researchers and policy makers to define the scope, set targets, and assess the progress of eco-city programs. Disaggregated sectoral-level indicators can provide the greatest amount of information and can serve as the foundation for future planning and action (Zhou, Price et al. 2011). Based on an extensive literature review of publicly available indicator systems, we have selected for analysis five academically researched indicator systems, two adopted by the central government, and four introduced by local governments. Those systems are selected based on the merits that: first, they are already adopted by the governments or widely quoted by the researchers; second, they represent the efforts either from central governments or local governments; third, the indicators and their implementation are publicly available. The 11 indicator systems are examined in the following discussion. The groups or cities that developed each system, key features and application of the system, and sources are summarized in Table 6.

Among the 11 selected systems, the sustainable development system, developed by the Chinese Academy of Sciences (CAS), has the greatest number of indicators: 146 indicators pertaining to support for the ecosystem, development, environment, society, and intelligence security. The Caofeidian eco-city indicator system, developed by Sweden's Sweco in cooperation with Tsinghua Urban Planning Institute, contains 141 indicators related to city function, building and the building industry, traffic and transportation, energy, waste, water, landscape, and public spaces. The indicator system for Tianjin Sino-Singapore eco-city has 22 controlled indicators and 4 directive indicators related to coordination with regional policy, the natural ecosystem, society and culture, and regional economics.

Table 6. Features of Indicator Systems Used in China

Indicator system	Application	Features	No. of indicators	Reference
Chinese Society for Urban Studies	MoHURD-developed standard. Still in development; application uncertain.	Indicators apparently chosen through participation of invited experts. Indicators are weighted.	45	Chinese Society for Urban Studies, 2011 (Li and Yu 2011)
China City Sustainable Development Indicators	CAS developed this indicator system to evaluate the sustainability of cities.	Indicators are divided into categories related to support of ecosystem, development, environment, social, and intelligence systems.	146	CAS, Niu W. et al. date
CAS (Research Center for Eco-Environmental Sciences)	Currently being applied to Yangzhou city.	Indicator categories, chosen through consultation with experts, include development status, development dynamic, and development ability.	25	(Wu, Wang et al. 2005)
Renmin University of China Tsinghua University	Borrowed from international indexes.	Index is compilation of several: human development index, social process index, ecological footprint, index for sustainable economic welfare, and material input per service unit.	5	Zhang, Wen et al., 2008.
MoC/MoHURD Eco-Garden City	MoHURD applies standards. Cities not measured against each other, but rather earn the designation Eco-Garden City.	Each indicator includes target threshold. Indicators chosen by team of experts. Calculation methods and criteria for each indicator provided in government notice.	19	(Ministry of Housing and Urban-Rural Development 2004)
State Environmental Protection Administration (SEPA)/MEP Ecological Province, City, County	SEPA sets standards for ecological cities. Cities not evaluated against each other, but rather attain designation as ecological cities.	Each indicator has target threshold. Indicators chosen by team of experts. Calculations for each indicator given in MEP notice.	22	MEP, 2007
Tianjin Eco-City	Key performance indicators developed by and applied only to Tianjin.	Indicators selected by planners.	22 +4	Tianjin city government, 2010
Caofeidian	Sweco in cooperation with Tsinghua Urban Planning Institute.	Indicator categories include city function, building and building industry, traffic and transportation, energy, waste, water, landscape, and public spaces.	141	Caofeidian city government
Turpan New District	Planning committee.	Indicator categories include	36	Turpan city

		societal, resource, and environmental. Indicators selected by planning committee.		government
Guiyang Eco-Civilization City	Guiyang city government.	Indicator categories include eco-economy, eco-environment, people's livelihoods, infrastructure, eco-culture, clean and efficient functioning.	33	(Guiyang City 2008)

Note: This is not a comprehensive list; selected indicator systems are those adopted by a government entity or under discussion in the policy research community.

The widely accepted criteria of SMART [19](Specific, Measurable, Achievable, Relevant and Time bound) is used in the paper to assess the selected indicators. *Specific* means indicators measure what they claim to measure and are not confounded by other factors. This is also referred to as "validity". *Measurable* shows indicator needs to be precisely defined; results should be the same regardless of who collects the data (a.k.a. verifiable); indicators that allow comparison over time and also from one location to another; the measurements used should be culturally, socially and politically acceptable to the population. *Achievable* refers to required data can actually be measured and collected. Feasibility should also be examined in terms of institutional capacity, and the cost of data collection is affordable and worthwhile. *Relevant* shows indicators must provide useful information to program and help guide decision-makers. *Time Bound* indicates the data should be collected and reported at the right time at regular interval, so the results could be updated at timely manner.

Applying the SMART criteria to those selected systems, although the indicator systems appear well designed, they all suffer some shortcomings. As Table 6 shows, some systems incorporate many indicators, complicating the effort to gather data and track progress and possibly resulting in dilution of the overall goal. Some systems contain few indicators, which may be insufficient to perform a comprehensive assessment. The system used for Zhang and Wen et al incorporates values from other comprehensive indicator systems such as the human development index (HDI), making it difficult to compare to the other systems. Some indicators, such as a city's energy security or energy self-sufficiency, may not represent appropriate goals within an area that has integrated energy markets. Energy self-sufficiency may not contribute to becoming low carbon, if the self-sufficiency is based on high-emissions coal. Some indicator systems focus more on conventional environmental pollutants rather than energy consumption or carbon emissions, missing the key feature of a low-carbon city.

Some indicators are qualitative, others quantitative, based primarily on the category of indicators, not the indicator system. In Tianjin, qualitative indicators were introduced to Caofeidian's proposed systems to incorporate social aspects of the evaluation. Even for difficult-to-quantify social aspects, quantitative methods such as percentages, polar questions, and satisfaction rates are used to create quantitative

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[19] SMART is a mnemonic used to set objectives, often called Key Performance Indicators (KPIs), for project management, performance management and progress evaluation. It was known first used by George T. Doran in November 1981 issue of Management Review.

scales that enable comparisons of social data from different cities. We found a wide variation among the methodologies for selecting indicators. Expert experience and judgment may be involved in deciding which indicators to use or how to weight them. External expert review is introduced for the indicators described in the MoHURD Chinese Society for Urban Studies Report (2011). Some indicator systems also created weighting factors to prioritize and differentiate the indicators.

From all the indicator categories adopted by Chinese governments or proposed by Chinese researchers, we selected 8 we believe to be key categories—energy, water, air, waste, transport, economy, land use, and social aspects—to discuss in detail. Table 7 summarizes coverage of the 8 categories by our 11 selected indicator systems. 130 indicators of those 11 indicator systems are organized within subcategories in the 8 categories. Indicators for each of the 8 categories are described in detail below, along with the different timeframes and units used for each indicator.

Table 7. Categories Covered in Indicator Systems

Category	Energy	Water	Air	Waste	Transport	Economy	Land Use	Social Aspects
Chinese Society for Urban Studies	×	×	×	×	×	×	×	×
CAS/China City Sustainable Development Indicators	×	×	×			×	×	
CASS (Zhuang, Pan, and Zhu, 2011.)	×							
RUC (Zhang, Wen et al. 2008)						×		×
CAS (Wu and Wang, 2005)	×	×	×	×		×	×	×
MoC/MoHURD Eco-Garden City		×	×	×	×		×	
SEPA/MEP Ecological Province/City/ County	×	×	×	×			×	
Tianjin Eco-city	×	×	×	×	×		×	
Caofeidian	×	×	×	×	×		×	
Turpan New District			×					
Guiyang Eco-Civilization City	×	×	×	×	×	×	×	×
Totals	8	8	9	7	5	5	8	4

Note: The statistics are indicative.

As Table 7 shows, most indicator systems include air, energy, water, land use, and waste. Transport and economic categories are less used, and social aspects are covered least often in the selected systems. Clearly, current systems focus on the physical environment, in which air, energy, water, and land use are the major components. Indicator systems for the Chinese Society for Urban Studies and for the Guiyang eco-civilization city include all eight categories, whereas the CASS indicator system covers only energy (Zhuang, Pan et al. 2011). Other systems have different focuses: for example, the RUC/Tsinghua indicator system for they stresses social and economic factors. Only the CASS indicator system has a strong focus on energy and carbon and therefore on low-carbon development (Zhuang, Pan et al. 2011).

4.2. Key Elements of Indicator Systems

Figure 1 shows the number of indicators appear in each of the 8 major categories in the selected indicator systems.

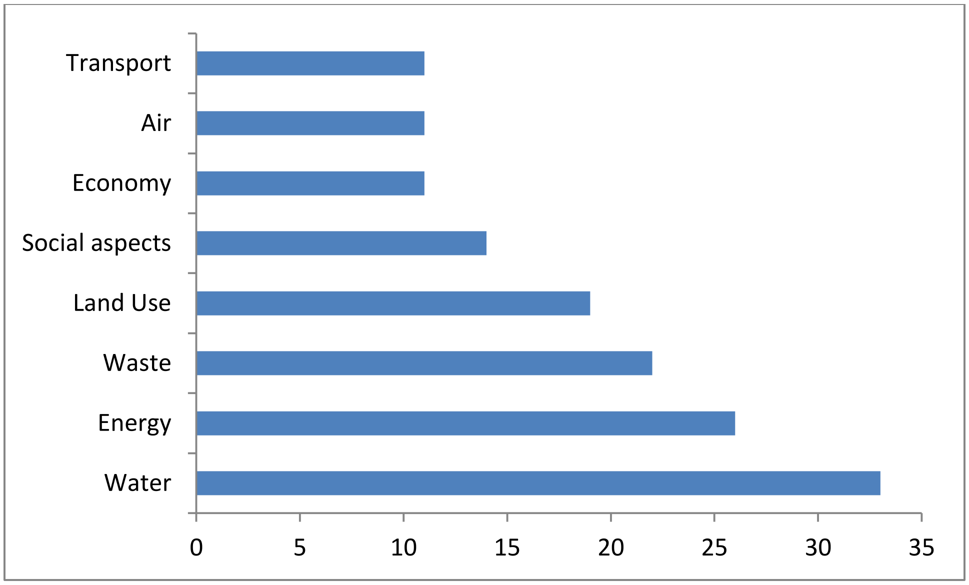

Figure 1. Numbers of Indicators by Major Category

In all 11 systems, the water category has the largest number of indicators (33), followed by energy, waste, and land use. This occurrence reflects the importance the developers of the indicator systems placed on those elements in evaluating the sustainability of a city. Both water and energy are basic inputs to a city, and waste, the byproduct of human activities, must be disposed of. Those top three indicators receive comprehensive evaluation. The indicators for carbon emissions are integrated into the energy category. Only the systems for Tianjin city and Caofeidian include carbon intensity indicators. Although carbon productivity and carbon emissions per capita or per GDP are included in the other indicator systems, they are compared with national standards, without proposing any city-specific criteria. Air quality and transport, with 9 indicators each, have the fewest indicators among the 8 major categories.

Exploring the 8 categories in more detail, Figure 2 shows how many of the 11 selected systems include various indicator subcategories. The number of subcategories included within a major category gives an indication of the importance placed on that category.

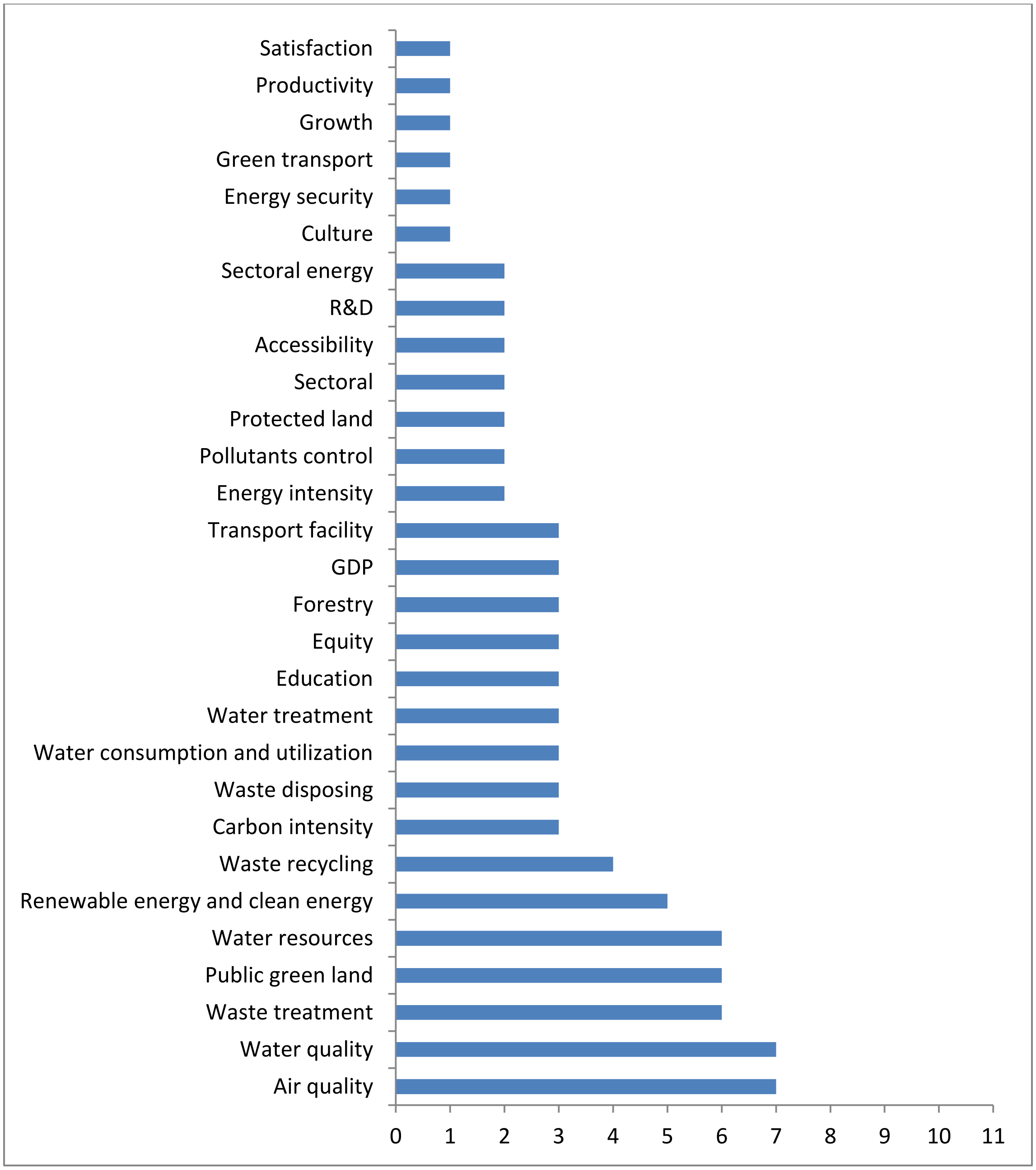

Figure 2. Numbers of Indicator Systems that Contain Various Subcategories

As Figure 2 shows, the most commonly used subcategories, by 7 out of 11 indicator systems, are air quality, and water quality, followed by waste treatment, water resources and public green land used in 6 out of 11 systems. These data show that the 11 selected indicator systems focus on conventional environmental factors. Carbon intensity is included in 3 systems and energy intensity in only 2, meaning that low-carbon eco-cities are not evaluated on the basis of carbon emissions and mitigation, which are the central targets for development and assessment. Although some subcategories, such as culture, green transport, productivity, general satisfaction, and other social-economic indicators, are included in only 1 system, that does not mean those factors are less important. Integrating those indicators with low-carbon features could enrich the assessment of low-carbon eco-city development. However, it also represents the challenges that not all the indicators are connected to “low carbon” feature, therefore, it helps to reflect the question over what need to be included in a “low-carbon eco-city” indicator system. The following sections describe the indicators used to assess each of the 8 major categories found in the 11 indicator systems. The features of the general categories and identified subcategories are provided, along with their units of measure and assessment criteria. The number of indicators in each subcategory is given in parentheses beneath the subcategory. We applied this method to all 8 major categories.

The columns headed Notes in the following tables identify the various indicators as controlled, binding, management, planning, or research. The identification indicates how strictly an indicator is implemented. The target or standard identified by a controlled indicator, for example, is mandatory once the indicator system has been adopted by the government and passed through the legislative body, which in China is the national or local People’s Congress. Planning indicators are those considered targets in city or regional planning, used to guide development strategy but not made mandatory. Binding indicators are not as strict as controlled indictors but are policy tools for the government to set up restrictions or targets to a certain indicator, therefore has legal effectiveness. Management and research indicators usually are included for reference. Controlled and planning indicators dominate the selected systems, suggesting that policy makers intend to exercise some degree of control over implementing the indicators.

4.2.1. Energy

In Table 8, energy indicators are grouped by subcategory according to the issues addressed. For each indicator, we present the units of the indicator and the criteria or target for assessment. We also include the source of the indicator used and the indicator type. The number of indicators in each subcategory is given in parentheses beneath the subcategory.

Table 8. Energy Indicators

Subcategory	Indicator	Units	Criteria	Source	Notes
Energy (2)	Energy productivity	10,000 GDP/tce	1.6 (2010) 2.8 (2020)	(Wu, Wang et al. 2005)	Research
	Energy consumption per GDP	tce/10,000 GDP	≤0.9	MEP	Binding
Carbon (7)	Carbon productivity	10,000 GDP/t CO_2	20% above average;	Zhuang, Pan, and Zhu, 2011	Research
	Energy consumption for key industrial product or carbon emission per capita of industrial addition	N/A	national average	Zhuang, Pan, and Zhu, 2011	Research

	Average carbon emission per capita	t CO_2/person	low carbon = <5;
			medium = 5-10;
			high = >10
				Zhuang, Pan, and Zhu, 2011	Research

	Average carbon emission per capita	t CO_2/person	low carbon =	Zhuang, Pan,	Research

	by residence		<5/3; medium = 5/3-10/3; high = >10/3	and Zhu, 2011	
	Emission factor	N/A	<national average	Zhuang, Pan, and Zhu, 2011	Research
	Carbon emissions per GDP	tC/million USD	150	Tianjin	Controlled
	Total carbon emissions by transportation	kgCO_2/capita/km	20	Caofeidian	Planning
Sectoral energy use (9)	Commercial building electricity consumption	kWh/m^2/yr	50	Caofeidian	Management
	Commercial building heating	kWh/m^2/yr	15	Caofeidian	Management
	Commercial building air conditioning	kWh/m^2/yr	20	Caofeidian	Management
	Residential building electricity consumption	kWh/m^2/yr	25	Caofeidian	Management
	Residential building heating	kWh/m^2/yr	45	Caofeidian	Management
	Residential building air conditioning	kWh/m^2/yr	0	Caofeidian	Management
	Total energy (including transportation)	kWh/capita/yr	10,000	Caofeidian	Planning
	Electricity	kWh/capita/yr	3,500	Caofeidian	Planning
	Government/Public building energy consumption per unit	kWh/m^2/yr	<90	(Li and Yu 2011)	Research
Energy security (1)	Rate of self-sufficiency	%	80	Caofeidian	Planning
Renewable energy and clean energy (7)	Renewable power production/total power consumption	%	85	Caofeidian	Planning
	Non-fossil fuel in primary energy	%	low = >20; medium = 10-20; high = <10	Zhuang, Pan, and Zhu, 2011	Research
	Renewable energy utilization rate	%	≥20	Tianjin	Controlled
	Proportion of renewable energy (excluding transportation)	%	95	Caofeidian	Planning
	Renewable/total energy (transportation)	%	75	Caofeidian	Planning
	Utilization rate for clean energy	%	>50	(Guiyang City 2008)	Controlled
	Renewable energy utilization rate	%	≥15	(Li and Yu 2011)	Research

Five subcategories often included in the energy category are renewable and clean energy, energy security, carbon intensity, energy intensity, and sectoral energy (see Table 8). The sectoral subcategory is dominated by indicators for residential and commercial buildings, electricity, heating, and air-conditioning. The indicator of “energy self-sufficient rate” reflects the degree of energy security. Energy security is important to China because China’s dependence on oil imports reached 57% in 2011. Although the country is a net importer of all forms of fossil energy, it is debatable whether energy self-sufficiency should be a central consideration at the city level.

Only 7 indicators are connected directly with carbon emissions or carbon intensity, which are under-represented in the overall evaluation system for low-carbon eco-cities. The carbon indicators that are used are mostly research types, meaning they have not reached the point of policy design or implementation. Indicators for renewable and clean energy are increasingly important, as China's use of renewable energy has skyrocketed in recent years. China's wind energy capacity has increased from 1.3 gigawatts (GW) in 2005 to 62.7 GW in 2011. China's solar capacity has reached 3 GW from almost nothing, although much is wasted because of variable generation or disconnection from with the grid. China has established the ambitious targets of producing 150 GW of wind and 20 GW of solar energy by 2020, and cities are on track with committed to the national targets.

The units used for energy and carbon indicators are in terms of productivity, intensity, or a per-capita measures. Cities themselves have established no hard caps for energy consumption or and carbon, although the Chinese government has proposed a national cap of 4 billion coal equivalent by 2015. Because the Twelfth Five-Year Energy Saving and Emission Reduction Plan[20] proposes a cap that will be aggregated through local governments and key industries, the low-carbon cities must develop cap indicators to meet that requirement. The units for the building sector are the standard kilowatt-hours (kWh) of electricity use per area per year. The units for renewable and clean energy targets are mostly percentages, with criteria that are consistent with national targets.

4.2.2. Water

Subcategories identified in the water category include water resources, water quality, water consumption and utilization, and water treatment (see Table 9). Water resource indicators assess the availability of water. According the Wang Shucheng, former head of China's Ministry of Water Resources, more than 400 cities have water supply shortages, 110 of them severe, and nearly two-thirds of all cities experience water shortages to some extent.[21] Therefore, cities place a priority on guaranteeing water supplies by extending the water supply infrastructure while also utilizing more recycled or reclaimed water. Caofeidian and MoHURD address the utilization of reclaimed water and recycling water. Tianjin's indicator system includes the natural water cycle and unconventional water resources. MEP views industrial waste water as a major source of recycled water.

Water consumption and utilization indicators evaluate the efficiency of fresh water use by units of consumption per capita or per unit GDP, with some indicators adding a timeframe of per day or per year. All indicator systems stress water quality, including the quality of tap water, drinking water, surface water, and underground water. Water quality standards are set by the Environment Quality Standards for Surface Water (GB3838) and the GB3838 standard IV is widely quoted for water quality in industrial regions. The criteria set by MEP, the environmental regulator, generally are higher than those of the indicator systems. The urban sewage treatment rate is set at 85% by MEP and 70% under MoHURD, for example. Because many indicators in the water category are based on rate or intensity, percentage units commonly are used.

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[20] See Section 5, Article 15 of NDRC, Twelfth Five-Year Energy Saving and Emission Reduction Plan. http://www.gov.cn/zwgk/2011-09/07/content_1941731.htm (in Chinese).

[21] Wang Shucheng, China's water resources security problems and solutions. Study Times. http://www.studytimes.com.cn:9999/epaper/xxsb/html/2009/06/22/01/01_50.htm (in Chinese).

Table 9. Water Indicators

Subcategory	Indicator	Units	Criteria	Source	Notes
Water resources (11)	Penetration of running water	%	100 (24 hr)	MoHURD Eco-Garden City	Binding
	Utilization of reclaimed water	%	≥30	MoHURD Eco-Garden City	Binding
	Rate of rain storage	%	90	Caofeidian	Planning
	Extent of wetland	%	1	Caofeidian	Planning
	Water supply source (surface/run off)	%	>70	Caofeidian	Planning
	Recyclable waste water	%	<10	Caofeidian	Planning
	Industrial water recycling rate	%	≥80	MEP	Binding
	Industrial water recycling rate	%	>75 (2012)	(Guiyang City 2008)	Controlled
	Net loss of natural wetlands	N/A	0	Tianjin	Controlled
	Utilization of reclaimed water	%	≥30	(Li and Yu 2011)	Research
	Industrial water recycling rate	%	>90	(Li and Yu 2011)	Research
Water consumption and utilization (6)	Fresh water consumption per unit of industrial added value	m^3/10,000 GDP	≤20	MEP	Binding
	Effective utilization coefficient of irrigation water	m^3/10,000 GDP	≥0.55	MEP	Binding
	Daily water consumption per capita	L/capita/day	≤120 (2013)	Tianjin	Controlled
	Utilization rate of non-conventional water resources	%	≥50 (2020)	Tianjin	Controlled
	Hot water temperature	℃	70	Caofeidian	Management
	Water consumption per capita per day	L/capita/day	100~120	Caofeidian	Planning
Water quality (13)	Compliance rate for quality of centralized source of drinking water	%	100	MEP	Binding
	Portion of regional water quality greater than level 3	%	80% (2010) 95% (2020)	(Wu, Wang et al. 2005)	Research
	Water quality and near-shore water quality	n/a	Meets functional area standard, and no water quality worse than standard V.	MEP	Binding
	Water quality meets functional area	%	100	MoHURD Eco-Garden City	Binding

	compliance rate				
	Comprehensive compliance rate for quality of city pipeline water	%	100	MoHURD Eco-Garden City	Binding
	Tap water compliance rate	%	100	Tianjin	Controlled
	Quality of local surface water	N/A	Meets GB3838 water quality standard IV (2020).	Tianjin	Controlled
	Water quality	N/A	Meets GB3838 water quality standard IV.	Caofeidian	Management
	Underground water quality	N/A	Meets GB3838 water quality standard IV	Caofeidian	Management
	Quality compliance rate of primary drinking water source	%	100 (2012)	(Guiyang City 2008)	Controlled
	Compliance rate of running water quality	%	100	Caofeidian	Planning
	Quality compliance rate of primary drinking water source	%	100	(Li and Yu 2011)	Research
	Water quality meets functional area compliance rate	%	100	(Li and Yu 2011)	Research
Water treatment (3)	Urban sewage treatment rate	%	≥70	MoHURD Eco-Garden City	Binding
	Urban sewage treatment rate	%	≥85	MEP	Binding
	Urban sewage treatment rate	%	>90 (2012)	(Guiyang City 2008)	Controlled

4.2.3. Air

The category of air quality and pollution control contains fewer indicators than do water and energy (see Table 10). Some national or regional air quality standards are provided as benchmarks for addressing indoor, downtown, or regional air quality. Air quality standards are set by the Ambient Air Quality Standard (GB3095)[22] and the Air Quality Index (AQI).[23] According to MEP's *Report on China's 2010 Environmental Status,*[24] among the 471 cities at county level or above that have air quality monitoring, 3.6% meet the highest quality level 1, 79.2% meet level 2, 15.5% meet level 3, and 1.7% fall below level

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[22] MEP, Ambient air quality standard. GB 3095-1996. http://www.mep.gov.cn/pv_obj_cache/pv_obj_id_F19CD6DB535D112F1994064E21C590D9D60E0300/filename/5298.pdf (in Chinese).

[23] MEP, Technical Regulation on Ambient Air Quality Index (on trial). http://kjs.mep.gov.cn/hjbhbz/bzwb/dqhjbh/jcgfffbz/201203/t20120302_224166.htm (in Chinese).

[24] MEP, Air Environment in the Report on China's 2010 Environmental Status. http://jcs.mep.gov.cn/hjzl/zkgb/2010zkgb/201106/t20110602_211579.htm (in Chinese).

3, demonstrating the severity of the air quality problem for cities. Where air quality has become a regional, not just a city, problem, only MEP and Tianjin have indicators that address regional air quality. Guiyang focuses on downtown air quality, and Caofeidian assesses at indoor air quality. MEP and Guiyang also have indicators for pollutant discharge and control measures, but those emphasize traditional pollutants such as SO_2. No indicators among the 11 systems examined include indicators for NO_X, mercury, or other pressing new pollutants. Regional air pollution and control of new pollutants must be addressed in future indicator systems.

Table 10. Air Quality Indicators

Subcategory	Indicator	Units	Criteria	Source	Notes
Air quality (10)	Air quality index (annual percent of days that exceed level 3)	%	95% (2010, 2020)	(Wu, Wang et al. 2005)	Research
	Quality of air environment	n/a	Meets functional area standard	MEP	Binding
	Days of air pollution index ≤100	days	≥300	MoHURD Eco-Garden City	Binding
	Regional air quality	days	Better than level II; ≥310 (85%) meets GB3095 standard (2013)	Tianjin	Controlled
	Compliance rate for downtown air quality	%	95(2012)	(Guiyang City 2008)	Controlled
	Indoor air quality: radon	Bq/m^3	<50	Caofeidian	Planning
	Indoor air quality: nitride	Bq/m^3	<70	Caofeidian	Planning
	PM10 daily average density (annual days that exceed level 2)	days	≥347	(Li and Yu 2011)	Research
	SO_2 daily average density (annual days that exceed level 2)	days	≥347	(Li and Yu 2011)	Research
	NO_2 daily average density (annual days that exceed level 2)	days	≥347	(Li and Yu 2011)	Research
Pollutant control (2)	Intensity of discharge of major pollutants (COD/SO_2)	kg/10,000 GDP	<4.0/<5.0	MEP	Binding
	Total emission of SO_2	10,000 ton	<18 (2012)	(Guiyang City 2008)	Controlled

4.2.4. Waste

Indicators for waste fall into three major subcategories: recycling, treatment, and disposal (see Table 11). Among the three subcategories, waste treatment receives the largest number of indicators. Almost all the selected systems have waste treatment indicators, some focused on garbage or industrial solid waste, others on hazardous waste. According to the Report on China's 2010 Environmental Status, national industrial solid waste discharge was 2.4 billion tons in 2010, the comprehensive utilization rate of garbage was 67.1%, and the disposal rate was 23.8%. Hazardous waste discharge was 15.9 million tons with a comprehensive utilization rate of 61.5%. Because the disposal of hazardous waste is both important and challenging, the indicators for hazardous waste control are more binding than others, which generally apply only to planning. MEP and Tianjin have addressed the harmless treatment of hazardous waste. Other indicators evaluate the rate and frequency of waste recycling and the energy consumed or generated by waste processing.

MEP has a series of solid waste pollution control standards[25] that include garbage discharge, hazardous waste, industrial waste, and solid wastes from certain processes or imports. The indicators incorporate MEP's standards as criteria for assessment. Caofeidian has detailed indicators for various waste process methods, which inform the growing debate over landfill or waste incineration. The units used in this category are per capita within a given timeframe, for example a year or a day. Percentages commonly are used for rate-based indicators.

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25 MEP, Catalog of Solid Waste Pollution Control Standard.
http://kjs.mep.gov.cn/hjbhbz/bzwb/gthw/gtfwwrkzbz/200412/t20041229_63465.htm (in Chinese).

Table 11. Waste Indicators

Subcategory	Indicator	Units	Criteria	Source	Notes
Waste disposal (4)	Daily waste per capita	kg/capita/day	≤0.8 (2013)	Tianjin	Controlled
	Comparable area total waste per capita	kg/capita/yr	438 (2007); 328 (2020)	Caofeidian	Planning
	Comparable area recyclable solid waste per capita	m^3/capita/yr	3	Caofeidian	Planning
	Animal waste resource rate	%	70% (2010); 90% (2020)	(Wu, Wang et al. 2005)	Research
Waste treatment (9)	Urban garbage harmless treatment rate	%	80% (2010); 100% (2020)	(Wu, Wang et al. 2005)	Research
	Hazardous waste and garbage (harmless) treatment rate	%	100 (2013)	Tianjin	Controlled
	Hazardous waste and garbage (harmless) treatment rate	%	≥90	MEP	Binding
	Industrial solid waste utilization and treatment rate	%	≥90	MEP	Binding
	Harmless treatment rate of garbage	%	≥90	MoHURD Eco-Garden City	Binding
	Rate of landfill waste	%	<10	Caofeidian	Planning
	Rate of waste incineration	%	>50	Caofeidian	Planning
	Rate of biological processing	%	>80	Caofeidian	Planning
	Rate of harmless treatment of garbage	%	>95 (2012)	(Guiyang City 2008)	Controlled
Waste recycling (9)	Rate of waste recycling	%	≥60 (2013)	Tianjin	Controlled
	waste recycling frequency	times/day	N/A	Caofeidian	Management
	Rate of hazardous waste recycling	%	100	Caofeidian	Planning
	Rate of waste recycling	%	>60	Caofeidian	Planning
	Per-capita energy demand for waste collecting, transporting, and processing	kWh/capita/yr	<500	Caofeidian	Planning
	Per-capita energy from waste processing (incineration, biogas, or landfill gas)	kWh/capita/yr	>500	Caofeidian	Planning
	Comprehensive rate of industrial waste utilization	%	>62 (2012)	(Guiyang City 2008)	Controlled
	Residential waste utilization rate	%	≥70	(Li and Yu 2011)	Research
	Comprehensive rate of industrial waste utilization	%	≥95	(Li and Yu 2011)	Research

4.2.5. Transportation

Transport indicators address the condition, accessibility, and greenness (especially the accessibility) of transportation systems (see Table 12). Factors that make urban transportation in China particularly challenging are the high density of urban populations and the focus on the city as the center of economy, industry, government, and culture. The development of sustainable transport therefore is an essential part of a low-carbon eco-city. As seen in Table 12, Caofeidian has detailed indicators that rate the accessibility of office or home to nearby transportation hubs. MoHURD and Guiyang focus more on the infrastructure and ease of transport, measuring factors such as the average road area or bus availability and average speed of road transportation. Tianjin includes an indicator for green transport, but the definition of *green transport* is vague. The indicator systems lack some key parameters for defining and assessing a low-carbon and sustainable transport system, for example, rate of ownership of private cars, fuel economy of vehicles, travel times and distances, usage rate of public transportation, mass transportation, facilities for biking and walking, and smart transportation management systems. In order to achieve a low-carbon transport system, more research and practice is needed to incorporate those indicators.

Table 12. Transportation Indicators

Subcategory	Indicator	Units	Criteria	Source	Notes
Ease of transport (4)	Average road area per capita	m^2/person	9 (2012)	(Guiyang City 2008)	Controlled
	Buses per 10,000 person	buses/10,000 persons	15 (2012)	(Guiyang City 2008)	Controlled
	Average speed of primary and secondary roads	km/hr	≥40	MoHURD Eco-Garden City	Binding
	Average commute time	mins	≤30	(Li and Yu 2011)	Research
Green transport (2)	Percent of green transportation	%	≥30 (2013)	Tianjin	Controlled
	Percent of public transportation	%	≥50	(Li and Yu 2011)	Research
Accessibility (5)	Access to transportation system from major office area (walking distance < 600-800 m)	%	100	Caofeidian	Planning
	Accessibility of residential areas to public transportation (walking distance < 800 m)	%	90	Caofeidian	Planning
	Accessibility of office place to public transportation (walking distance < 800m)	%	90	Caofeidian	Planning
	Difference in time/distance to home/office time by public transportation vs. auto	%	<1.5	Caofeidian	Planning
	Difference in time/distance to home/office by biking vs. auto	%	<1.5	Caofeidian	Planning

4.2.6. Economy

The most common indicator for assessing the economy is the performance of the sectoral economy, especially the service sector, investment in R&D, or investment in fixed assets (see Table 13). Based on their belief that a low-carbon city should first be a low-carbon economy, Guiyang has set targets for the service sector, high-tech industry, R&D spending, and rural development. Wu and Wang (2005) address the productivity, or efficiency, of the economy in terms of quality-oriented economy development. Both Guiyang and Wu and Wang (2005) use GDP per capita and the growth rate of GDP to assess the economy. Other indicator systems pay little attention to economic factors. The indicators utilize midterm timeframes of 2015, and long-term timeframes of 2020, consistent with the timeframes of China's macro-economic plan. The criteria differ depending on the condition and background of each city. Without a robust economy, a low-carbon eco-city cannot be sustained. The indicator systems show the importance of per-capita GDP or the growth of GDP. The real question, however, is the quality of the economy and the level of its carbon emissions. The overall design of current systems lacks indicators for carbon. Recent research by the World Bank shows that China needs to implement structural reform and seize the opportunity to "go green" by encouraging investment in a range of low-pollution, energy- and resource-efficient industries (The World Bank 2012). Indicator systems must emphasize such features to support development of low-carbon economies.

Table 13. Economic Indicators

Subcategory	Indicator	Units	Criteria	Source	Notes
GDP (2)	Average GDP per capita	10,000 RMB	1.8 (2010); 5.8 (2020)	(Wu, Wang et al. 2005)	Research
	Average GDP per capita	RMB	34,600 (2012)	(Guiyang City 2008)	Controlled
Growth (1)	Annual growth rate of GDP	%	8% (2010); 7% (2020)	(Wu, Wang et al. 2005)	Research
Productivity (1)	Land productivity	10,000 RMB/km^2	1850 (2010) 4000 (2020)	(Wu, Wang et al. 2005)	Research
Sectoral (7)	Ratio of investment in fixed assets to GDP	%	33% (2010); 38% (2020)	(Wu, Wang et al. 2005)	Research
	Value of service sector in GDP	%	50 (2012)	(Guiyang City 2008)	Controlled
	Growth rate of high-tech industry	%	25 (2012)	(Guiyang City 2008)	Controlled
	Growth rate of average general budget revenues	%	12 (2012)	(Guiyang City 2008)	Controlled
	Ratio of R&D spending to GDP	%	>2 (2012)	(Guiyang City 2008)	Controlled
	Disposable income of urban residents	RMB	18,000 (2012)	(Guiyang City 2008)	Controlled
	Net rural per-capita income	RMB	6,000 (2012)	(Guiyang City 2008)	Controlled

4.2.7. Land Use

Most indicator systems address land use (see Table 14). MEP and Wu (2005) focus on protecting land and the natural system, whereas MoHURD, Tianjin, Caofeidian, and Guiyang focus on public green areas and the built environment. The per-capita share of green land and its accessibility are two of the most common indicators in the subcategory of public green land. The green land indicators of Caofeidian emphasize wetlands and natural land, reflecting the local presence of large wetland areas and plans for wetland protection. The indicator system of Wu (2005) proposes the restoration of degraded land, with an emphasis on land use and ecosystem health.

Land supports city development. According to MoHURD's Code for Classification of Urban Land Use Classes and Planning Standards of Development Land,[26] a reasonable land use structure for cities is: 25%-40% residential, 5%-8% administrative and public service, 15%-30% industrial, 10%-30% streets and transportation, and 10%-15% green space. Industrial land use in China's cities exceeds the stated standard, while green space is less than the standard. As shown in Table 14, the selected indicator systems have established high targets for green land. The systems do not, however, clearly define *green land*. A commonly used indicator is forest coverage, but some also include parks, protected lands, and open spaces. A consistent, precise definition needs to be developed for future indicator systems.

Table 14. Land Use Indicators

Subcategory	Indicator	Units	Criteria	Source	Notes
Forestry (2)	Forest coverage	%	25% (2010)	(Wu, Wang et al. 2005)	Research
	Forest coverage	%	45% (2012)	(Guiyang City 2008)	Controlled
Protected lands (3)	Recovery rate of degraded land	%	96% (2010) 100% (2020)	(Wu, Wang et al. 2005)	Research
	Rate of protected arable land	%	15% (2010) 20% (2020)	(Wu, Wang et al. 2005)	Research
	Percentage of protected area	%	≥17	MEP	Binding
Public green land (14)	Average per-capita public green land	m^2/capita	≥12 (2013)	Tianjin	Controlled
	Average per-capita public green land	m^2/capita	≥11	MEP	Binding
	Green coverage in built-up area	%	≥45	MoHURD Eco-Garden City	Binding
	Per-capita public green space in built-up area	m^2/capita	≥12	MoHURD Eco-Garden City	Binding
	Rate of green land in built-up area	%	≥38	MoHURD Eco-Garden City	Binding
	Green land in total area (including water landscape)	%	35	Caofeidian	Planning
	Average per-capita public green land	m^2/capita	20	Caofeidian	Planning
	Percentage of wetland and natural land in green land	%	20	Caofeidian	Planning
	Residence accessible to parks and public spaces within less than 3,000 m	%	100	Caofeidian	Planning
	Accessible to city green land (>10 ha) in less than 1,000 m	%	100	Caofeidian	Planning
	Residence accessible to shoreline or river banks in less than 1,000 m	%	100	Caofeidian	Planning
	Average per-capita public green land	m^2/capita	≥10 (2012)	(Guiyang City 2008)	Controlled
	Rate of green land in built-up area	%	≥40	(Li and Yu 2011)	Research
	Accessible to city green land in less than 500 m	%	≥80	(Li and Yu 2011)	Research

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[26] See more on the MoHURD notice: http://www.mohurd.gov.cn/gsgg/gg/jsbgg/201201/t20120104_208247.html (in Chinese).

4.2.8. Social Aspects

Social indicators in the systems examined here focus primarily on equity and education (see Table 15). Wu and Wang (2005) and Guiyang are the only two indicator systems that give significant consideration to social aspects. Indicators representing social interaction with the environment include the rate of satisfaction with the environment and public participation in environment. Social equity indicators include the Gini coefficient, social insurance, or unemployment rate. Because most social indicators are rate-based, percentages generally are used. All the listed indicators are time-sensitive, based on a certain time point or multiple timeframes.

Table 15. Social Indicators

Subcategory	Indicator	Units	Criteria	Source	Notes
Satisfaction (1)	Public satisfaction with the environment	%	90% (2010); 95% (2020)	(Wu, Wang et al. 2005)	Research
R&D (2)	Percentage of personnel in R&D	%	14% (2010); 18% (2020)	(Wu, Wang et al. 2005)	Research
	Percentage of spending on R&D in R&D	%	≥2	(Li and Yu 2011)	Research
Education (5)	Average years of education for adults	yr	12 (2010); 14 (2020)	(Wu, Wang et al. 2005)	Research
	Average years of education	yr	>10 (2012)	(Guiyang City 2008)	Controlled
	Public eco-civilization literacy and participation rates	%	100 (2012)	(Guiyang City 2008)	Controlled
	Public environmental literacy and participation rates	%	75% (2010); 90% (2020)	(Wu, Wang et al. 2005)	Research
	Fiscal spending on education in GDP	%	≥4	(Li and Yu 2011)	Research
Equity (4)	Sex ratio at birth	Girls=100	100-108 (2012)	(Guiyang City 2008)	Controlled
	Gini coefficient inverse	N/A	2.6 (2010); 2.9 (2020)	(Wu, Wang et al. 2005)	Research
	Coverage of social insurance	%	>80 (2012)	(Guiyang City 2008)	Controlled
	Registered urban unemployment rate	%	<4.5 (2012)	(Guiyang City 2008)	Controlled
Culture (1)	Cultural industry in GDP	%	4 (2012)	(Guiyang City 2008)	Controlled

The development of low-carbon eco-cities involves numerous social aspects, for instance city leadership, education, connectivity, lifestyle, public participation, culture, risk and crime, social insurance and welfare, and aesthetics. Although current systems contain no consistent indicators for the social category, in China's history city leadership has been vital to establishing an agenda, planning, mobilizing resources, and building capacity for development. The other aspects listed above also have their role in the social process. What should be included and how are central issues for future discussion.

4.3. Features of Indicators

The criteria incorporated in different indicator systems differ greatly. Timeframes are useful when a target is set for a specific indicator. As shown in Figure 3, the systems examined here most commonly use single criteria without a specified time point, which means that once a city has reached a given threshold, it is seen as meeting the associated assessment requirement. Other systems set a target for a certain year or multiple timeframes, generally 2015 or 2020 in accordance with the timeline for China's five-year plans. Low, medium, and high target ranges are defined for some indicators. The timeframe for other criteria are not specified but are connected to average national or regional standards or targets, usually at the high end of the relevant standards.

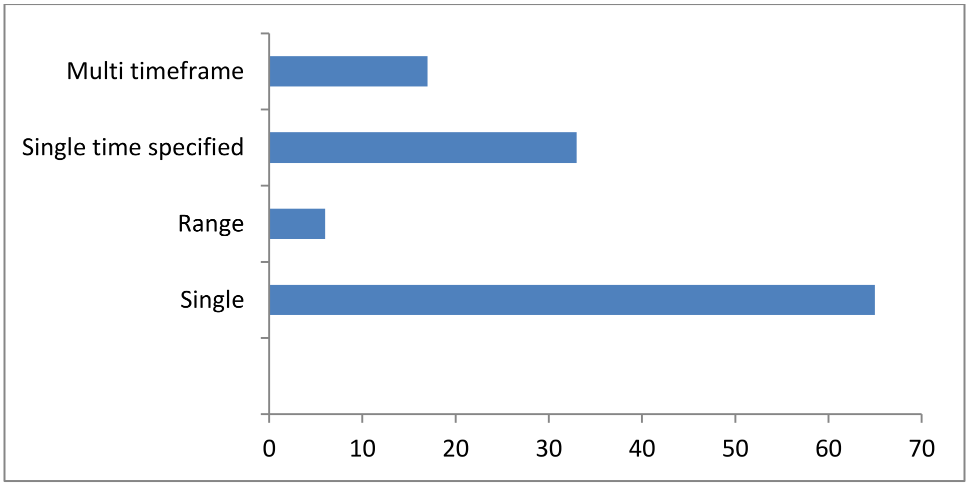

Figure 3 Numbers of Indicators at Various Timeframes

The information pertaining to the criteria for various indicators derive primarily from three sources. One source is national or regional standards, if they exist. For example, there are national standards for both air and water quality, and cities typically, but not always, adopt criteria at the high end of those standards. A second source is industrial or sector-wide best practices, such as for commercial or residential building energy consumption. Other targets are driven by city or local conditions or performance needs. The utilization rate for renewable energy, for instance, may be based on the city-level availability of resources and the target desired by the city government.

In some cases, standards and regulations themselves provide indicator benchmarks or targets. In rare cases, for example in the MEP system, cities are graded on each indicator, and the cities having the overall highest scores are named eco-cities. A problem with this system is that a city that is weak in certain key areas but that has a good overall score can earn the designation. Weighting and scoring systems need careful examination and design, although they are not yet used widely in the selected systems. The 11 selected systems contain many indicators that have not been categorized. The Guiyang system, for example, includes the efficiency of administrative services, the index of perception of corruption, and public satisfaction with the city administration. Because such indices are difficult to quantify, they are not examined in this analysis.

Data availability is another issue, because some indicators can be evaluated using data from statistical reports, while others require effort to set up a standard. Zhou et al. (2011) discuss the selection of data types and sources. In the international indicator systems review, Williams et al. also exam the data issue in detail (Williams, Zhou et al. 2012). Figure 4 shows the terms of measurement for the indicators from our selected systems.

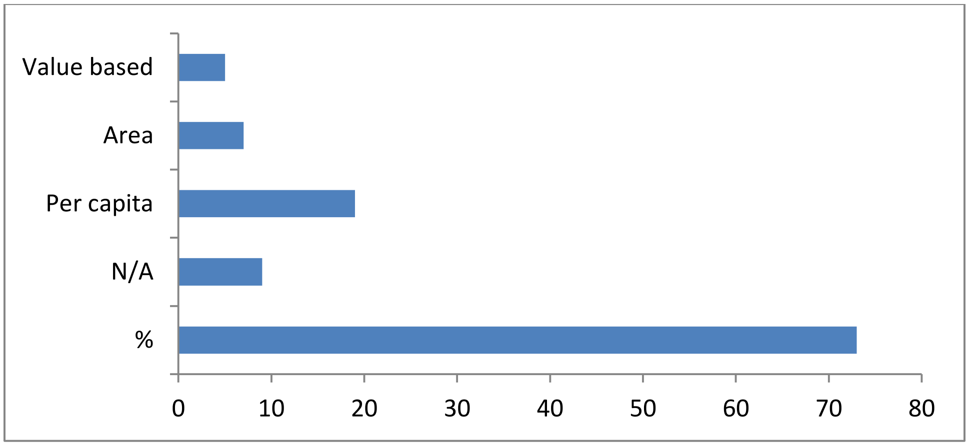

Figure 4. Number of Indicators by Units of Measure

5. Comparison to international indicator system

As part of the review efforts, the project also investigated 20 of the internationally used indicator systems (Williams, Zhou et al. 2012). Compared to the international indicator systems, the Chinese indicator systems have significant differences on the structure of categories of indicators, the concentration of specific types of indicators, the methodology and the weighing systems, and the purpose of applying the indicator systems.

The key findings on the structure of primary category and secondary category of both the Chinese and international systems are similar. The research shows there is consensus on the selection of primary categories, however, the specific indicators in each primary category vary significantly in the international systems investigated (Williams, Zhou et al. 2012). The primary categories, both in the international and domestic systems, are usually structured in environment (or ecology), economy and social aspects, which is consistent with the framework of sustainable development. Consensus has been focused on a few environmental categories, while social and economic goals are less commonly used. A few international cities were observed to introduce some new indicators such as happiness index in the system, while energy and carbon category is increasingly considered by city planners and policy makers in China.

The lack of commonality has been seen both in China and internationally, but the international indicator system has better representation of energy and carbon indicators. Within the 16 indicator systems analyzed in the international systems, only 10 indicators were common to more than 2 systems. The two most common indicators, “total water consumption in liters/capita/day” and “CO_2 emissions in tonnes/capita/day” were found in 7 systems (Williams, Zhou et al. 2012). In the Chinese indicator system review, 18 types of indicators are used by less than 2 systems, and only one indicator system highlighted energy and carbon indicators in the assessment. Conventional environmental factors of air, water, and waste are commonly used by the Chinese systems. This lack of commonality in the use of specific indicators is not surprising given the various goal and diversified condition of low carbon eco-city development, they rarely agree on the best means and necessary tools to assess development and measure progress.

Expert consultation is commonly used in building the indicator systems both in China and internationally, however, weighting methods are not widely applied. The systems are normally built by international organizations, research institutes and NGOs independently or work with government agencies to facilitate the development of low carbon eco-city or comparison among cities. This is even more common as the indicator systems are normally developed by the government owned research institutes under corresponding government agencies. Those institutions usually have expertise in some aspects of the urban development or city planning, and have good connection with the research community and government bodies. However, it is not clear yet if Delphi method, a systematic involvement and interpretation of expert view has been commonly used. Chinese systems normally have equal weighting for each selected indicators but the MEP system uses score system so to address the overall performance not specific indicator. Furthermore, public participation and stakeholder involvement in the process need to addressed in China. The transparency of the method, data, process, and assessment is crucial for a success indicator system.

Indicator systems are more used for ranking internationally while in China are more for assessment. Out of 16 international systems reviewed, 9 systems (more than half) ranked comparative performance between cities (Williams, Zhou et al. 2012). Those systems identified as ranking systems share some common features on the selected indicators and number of indicators so to make it comparable. Almost all Chinese indicator systems are used for assessment, which compares to the criteria set by the system so to decide if the city meet a certain standard therefore eligible for the program or check the status of building low carbon eco-city, and provide policy implications to fill the gaps. This feature shows the need for comparable indicator system in China and the potential difficulties in doing so.
In addition, both Chinese indicator systems and international systems have to meet the challenges of data availability and sources of data, and to face the tradeoffs in choosing indicators between comprehensive versus specific, quantitative versus qualitative, standardize versus adaptive, stable versus dynamic. The purpose of the indicator system, the method to adopt and the structure of the system will shape how the indicators are selected and used therefore will impact the application of the indicator systems.

6. Conclusion

The concept of a low-carbon city may provide a key to addressing the challenges of urbanization, specifically concerning climate change. China has moved aggressively through both the central and local governments to build policies and programs that support low-carbon eco-cities. China’s Ministry of Environmental Protection, National Development and Reform Commission, and Ministry of Housing and

Urban-Rural Development have developed independent indexes for the eco-city, low-carbon city, and low-carbon eco-city. In addition, provincial and city governments have developed major local initiatives. China's successes and failures in demonstrating and implementing the concept of the low-carbon eco-city may greatly affect how the world addresses climate change and sustainable development in cities. Because indicator systems are essential to defining a low-carbon eco-city, they are useful in assessing the development of such cities. There is no lack of indicator systems on papers, but there is lack of practical indicator system that policy makers can use in their decision making and make progress in the real assessment. Although multiple guidelines exist, it remains unclear what best defines a low-carbon eco-city; although more than 100 indicators have been used or proposed for assessment, few provide extensive coverage of energy use and carbon emissions. Policy makers and leaders, however, continue to demand comprehensive toolboxes to facilitate development of low-carbon eco-cities.

This paper presents the results of an extensive literature review of the development of low-carbon eco-cities in China. Our key findings show there is consensus on primary categories of the indicator systems, however, less agreed on the specific indicators in each primary category. The number of indicators, the methodology of selecting indicators and the way the indicator systems are used vary cross different systems further indicates lack of commonality in the design and implementation of those indicators. Through reviewing the key indicator systems used in China shows the current indicators are not SMART enough to meet the demand for joint efforts on low-carbon eco-city development in China. Specific, measurable, achievable, relevant and time bound --the SMART criteria-- we used to review the major categories of indicator systems, also acts as guideline for the proposal and section of indicators.

We provide qualitative and quantitative analysis of 11 major indicator systems that researchers, planners, governments, and city managers have used in China. The paper examines 8 major categories of indicators—energy, water, air, waste, transport, economy, land use, and social aspects. Although the indicator systems generally apply to broad categories, some focus on specific aspects. Developing policy tools for stakeholders in low-carbon eco-cities requires increasing the emphasis on indicators for energy and carbon emissions. Indicators that more fully characterize a city's energy consumption and consequent carbon emissions, in terms of end uses, fuels, and delivery systems, would be essential to identify emissions sources and mitigation potentials. In the next phase of research, we will compare Chinese practices with international best practices based on which indicator systems incorporate expert consulting and a weighting system. The observations and analysis of the current used indicatory system both in China and internationally would serve as a good foundation for future adoption or development of a transparent, systemic, and methodological indicator system.

The new system should have a clear vision of what defines a low-carbon eco-city. Those selected indicators should reflect the connection to such low carbon vision. They should be based on data availability, the international best practices but also given consideration of local situation. They should set achievable targets in given clear time frames so to make it possible to mobilize incentives and assess progress. They need to be embedded to the governance structure and institutional capability so the implementation is not only possible but also sustainable. They have to evolve with changing economic, social, and environmental situations so to adaptive to new frontiers. With careful examination and detailed comparison, a comprehensive, comparable, and adaptive indicator system can be developed and put to good use by policy makers.

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References

Chinese Society for Urban Studies, Ed. (2009). Chinese Low Carbon Eco-city Development Strategy. Beijing, Beijing City Press.

Chinese Society for Urban Studies, Ed. (2011). China Low-Cabon Eco-city Development Report 2011. Beijing, China Building Indsutry Press.

Guiyang City (2008). Guiyang city index system of ecological civilization city construction and monitoring methods. Guiyang.

Lei, H., G. Zhuang, et al., Eds. (2011). Low carbon cities: why and how? Beijing, China Environmental Science Press.

Li, H. and L. Yu (2011). "Chinese Eco-city Indicator Construction." Urban Studies **18**(7): 81-86.

Liu, Y., Y. Wang, et al. (2009). Chinese Low Carbon City Development Strategies. China Sustainable Development Strategy Report 2009. Chinese Academy of Sciences Sustainable Development Strategy Group. Beijing, Science Press.

Ministry of Environmental Protection (2007). Notice on the insurance of indicators for ecological county, ecological city, and ecological province.

Ministry of Housing and Urban-Rural Development (2004). Notice on implementation of creating "eco-garden city"

National Development and Reform Commission (2010). Notice regarding the pilot development of low-carbon province/region and low-carbon city. Division for Climate Change.

Qiu, B. (2009). "China's City Development Model Transformation Trend." City Development Research.

Suzuki, H., A. Dastur, et al. (2011). Eco2 Cities: Ecological Cities as Economic Cities. Washington DC, The World Bank.

The Climate Group (2010a). China's Clean Revolution 3: Cities. Beijing, The Climate Group.

The Climate Group (2010b). Low Carbon Cities -- An International Perspective. London, The Climate Group.

The World Bank (2012). China 2030: Building a Modern, Harmonious, and Creative High-Income Society Washington DC, The World Bank.

Wan, H., Ed. (2004). Eco-cities Paradigm Research, Beijing Normal University.

Williams, C., N. Zhou, et al. (2012). Measuring in All the Right Places: Themes in International Municipal Eco-City Index Systems. ACEEE 2012. Boston.

Wu, Q., R. Wang, et al. (2005). "The indices and the evaluation method of eco-city." Acta Ecologica Sinica **25**(8): 2090-2095.

Zhang, K., Z. Wen, et al. (2008). "Evaluation and Indicators of Ecocity: Theory, Method and Application."

Zhou, N., L. Price, et al. (2011). A Low Carbon Development Guide for Local Government Actions. Berkeley, Lawrence Berkeley National Laboratory.

Zhuang, G., J. Pan, et al. (2011). "Content of low-carbon economy and the comprehensive evaluation index system." Progress in Economics(1).