Ecological Indicators 48 (2015) 448–456

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

ELITE cities: A low-carbon eco-city evaluation tool for China

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ARTICLE INFO

Article history:
Received 18 April 2014
Received in revised form 23 July 2014
Accepted 8 September 2014

Keywords:
Low-carbon eco-city
Indicator system
Tool
ELITE cities
China

ABSTRACT

China is pursuing the development of low-carbon eco-cities to limit carbon dioxide and other greenhouse gases emissions; however, it is unclear what constitutes a low-carbon eco-city and how to evaluate it. The eco and low-carbon indicator tool for evaluating cities (ELITE cities) was developed by researchers at the Lawrence Berkeley National Laboratory in 2012 to evaluate cities' performance by comparing them against benchmark performance goals as well as rank them against other cities in China. ELITE cities measures progress on 33 key indicators selected to represent priority issues within eight primary categories. An excel-based tool was then developed to package the key indicators, indicator benchmarks, explanation of indicators, point calculation functions and transparency-oriented data recording instructions. ELITE cities could be a useful and effective tool for local city government in defining the broad outlines of a low-carbon eco-city and assessing the progress of cities' efforts towards this goal. ELITE cities can also be used by higher-level governments to assess city performance and discern best practices. This paper explains the general framework of the ELITE cities tool, the methods by which the indicators and indicator benchmarks were established, and a detailed guide on tool applications.

1. Introduction

China's cities are diverse: some rank among the world's most polluted and others are becoming epicenters of global green business development. However, high-speed growth is a unifying characteristic and uncontrolled urban expansion risks both exacerbating environmental problems and reducing the social and economic benefits of cities (Liu and Diamond, 2005). There are few tools available to define development and planning priorities, and to satisfy the need for monitoring and benchmarking, and comparatively assessing the impact of policies in different cities (Murakami et al., 2011; Price et al., 2013; Zhou and Williams, 2013; Zhou et al., 2012). This study aimed to create city-level performance indicators based upon globally proven strategies and apply them to the hundreds of Chinese cities that have declared goals for eco-city and low-carbon development with the support from China's Ministry of Housing and Urban-Rural Development (MOHURD). Although local governments around the world have pursued plans to minimize local and global environmental impacts, sustain economic growth and provide for harmonious social interactions, these efforts are largely recent and diverse and lessons may not be directly applicable to China. In this research, we first conducted an comprehensive review of existing well-known indicator systems and their indicators, based on which we have developed an indicator system and have studied international best practices and experience in each indicator, we then developed an excel-based tool to assist the evaluation of low-carbon eco-city developments in China (Zhou and Williams, 2013; Zhou et al., 2012). An overall performance score is the primary output of this tool, allowing a city's performance to be directly compared against benchmark goals, past performance, and the performance of other cities in China. The paper first introduces the framework and theories for the ELITE cities tool, then shows the indicator selection, rating and weighting process, and finally presents the selected indicators and their benchmark. The indicator system and tool have been tested and demonstrated by several Chinese cities, and can assist the cities in development low carbon eco-city plans with more focus on high potential areas, as well as to be used to evaluate the current status and the progress of a city.

2. Methods and data of the ELITE cites tool

We first conducted an intensive literature review on existing research on low-carbon eco-city and the indicator systems, including 16 international and 11 Chinese indicator systems. We categorized all indicators into eight major categories in a combined database, so as to investigate the commonly used indicators. We rated all the indicators based on the commonality and the specific,

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http://dx.doi.org/10.1016/j.ecolind.2014.09.018
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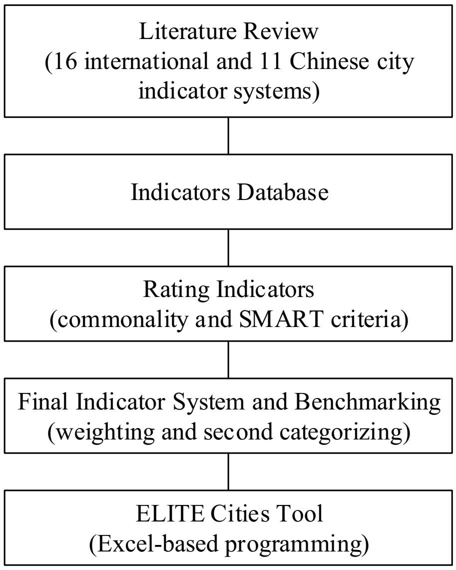

Fig. 1. The framework of the ELITE cities tool.

measurable, attainable, relevant, and time-bound (SMART) criteria. We then applied expertize in the selected 33 final indicators in eight categories, along with their benchmarks. The study framework is summarized in Fig. 1, and each process is explained in detail below.

2.1. Review of existing indicator systems

The study reviewed 16 international indicator systems and 11 Chinese indicator systems. A broad first-order search was conducted using the terms "eco-city", "green city", "sustainable city", "low-carbon city", "smart city", and "livable city" to find relevant indicator systems. The choice of indicator systems for this study was based upon their fit with the following criteria:

1) High-level relevance to sustainability, green cities, eco-cities, low-carbon, smart cities, and livability terminology;
2) Evaluations conducted at the national or sub-national level;
3) Clarity of indicator definitions;
4) Clarity of indicator selection criteria and methodology; and
5) High commonality of references in the reviewed literature.

If an indicator system has existed for several years, the most recent version was chosen on the assumption that the quality of the most recent version was better than past iterations. When a single organization was the author of multiple systems, only one was chosen to represent this organization, as was the case with the Economist Intelligence Unit's systems. We chose for evaluation 16 international systems at the sub-national level (1 neighborhood-level system, 14 city-level systems, and 1 provincial-level system) and 11 Chinese systems (2 national-level city assessments, 4 individual city-level systems, 5 research-oriented systems) were chosen for evaluation.

City-level sustainability indicator systems and efforts are found more widely in countries with a middle-level income and above than in developing countries. Upon reviewing the international literature, the following applications of the indicator systems were identified:

- Three indicator systems were applied to cities internationally (ESMAP, 2011; GCI, 2007; PriceWaterhouseCooper, 2011).
- Four systems were applied to cities across North America (Karlenzig and Marquardt, 2007; Marchington, 2011) and at the individual city level (Boston Indicators Project, 2012; Sustainable Seattle, 1993).
- Four systems were applied in Europe, with two applied to cities across the EU region (EU Green Capitals Program, 2011; Hakkinen, 2007) and two applied to cities nationally (Forum for the Future, 2010; MONET, 2009).
- Two systems were applied in Australia to cities nationally (Trigg et al., 2011) and to cities in specific states (Wiseman et al., 2006).
- Three systems were designed in whole or in part by researchers in other countries for application in Asia (EIU, 2011) and specifically China (Esty et al., 2011; Xiao et al., 2010).

The Chinese indicator systems evaluated are closely related to China's city hierarchy governance complexity (Chinese Society for Urban Studies, 2011).

Two indicator systems were proposed and implemented nationally (MEP, 2007; MOHURD, 2004)

Four were applied at the individual city level (Guiyang City, 2008; The Climate Group, 2010; Turpan New District Planning Committee, 2011).

Our literature review reveals that there is no consensus on a definition of eco-city, nor are there scientifically based criteria for evaluating eco-cities. The term "eco-city," and similar concepts such as "green" and "sustainable" cities, have evolved over time concurrent to the development of the understanding of social change and mankind's impact on environmental and economic health. The terms "green city," "sustainable city," and "eco-city" will likely continue to evolve as best practices for economic sustainability and social health evolve. In addition, evaluating a city's relationship to and impact on its environment, inhabitants, and the market is complex from a theoretical standpoint and challenging because data on eco-cities vary and cannot be easily compared. In sum, "eco-city" and similar terms are used subjectively. For this concept to usefully inform Chinese policy, eco-city goals that are specific to China should be developed.

Because the term "low-carbon eco-city" has only recently attained popularity in China and is not used elsewhere, there are no existing indicator systems to measure the performance of such a city. However, there is some high-level consensus on the types of phenomena that should be measured in evaluating sustainable, green, eco-, and similarly labeled cities. All indicator systems measure performance related to energy and climate change. Fewer, but still a majority, measure air quality and land use impacts. Even fewer, but still a majority, measure water quality and social health impacts. Waste, transportation, and economic impacts are least commonly measured, but nevertheless are measured by a majority of indicator systems.

Despite some consensus on the most important general categories to be measured, there is little consensus about the priority issues to be evaluated in each category. There is also little agreement on the methodology by which indicators for each of these areas should be chosen other than relying on data that are already available and on expert opinion regarding what indicators can best be used to measure progress. Threshold benchmarks are not commonly used, and there is little agreement on how indicators or indicator categories should be weighed against each other in forming an aggregated score that could be assigned to a city if a single summary indicator is desired.

2.2. Subdivision into primary categories and sub-categories

An initial attempt to isolate common indicators within each primary category found that no single indicator in these systems was common to more than half of these. In order to be found to be common, an indicator would have to have the exact same or functionally the same numerator and denominator. For example, although total primary energy per capita and total electricity per capita both measure per capita energy use, they are not treated as the same indicator because primary energy and electricity use two different measurement scopes. A high degree of discernment was used in this process when indicators were vaguely defined. For example, an indicator that was defined as "municipal solid waste per capita" would not be treated the same as an indicator that was defined as "waste per capita".

The lack of commonality of indicators among the systems analyzed mimics the findings of Tanguay et al. (2010) whose study of 17 municipal-level indicator systems found that 72% of indicators were used by only one system, and none were used by a majority of the systems (Tanguay et al., 2010).

The diversity of indicators used internationally to measure city efforts is caused in part because city-level sustainability goals are diverse and often highly contextualized by the specific drivers of environmental, economic, and social problems within the city or region; the time period in which the goals were established; the ability of the city to implement programs and policies; and a wide host of other factors such as climate, geography, political context, and others. Due to the dearth of real-world examples of successful low-carbon and eco-cities and these examples' varying individual circumstances, there is little agreement about the definition and scope of a low-carbon eco-city or which variables used can measure progress towards the often vague aspirational goals of such developments.

A top-down method was applied to begin discerning key priority areas common to sustainability theory and aspirational cities. Sustainability theorists often note three primary categories of current challenges to the sustainability of humankind: environmental, economic, and social. The literature review reveals that city-level challenges to sustainable development blur the lines between these categories, as human activities often have implications for all three (Zhou and Williams, 2013; Zhou et al., 2012). Although this issue of cross-categorization cannot be eliminated completely, to highlight the priority policy areas recommended by this study, these three categories have been disaggregated into eight primary categories commonly found in international indicator systems, measuring the quality of priority environmental resources (energy/climate, water, and air), activity drivers of environmental, social, and economic states (energy/climate, mobility, land use, and waste), and two separate economic and social health primary categories[1]. These primary categories have been applied as a means to organize the ELITE cities indicators and rating calculation methodology.

Given the lack of definitive findings of commonality through strictly matching indicator numerators and denominators, indicators within each primary category were reanalyzed for commonality according to sub-categories. Sub-categories were designed iteratively based on the underlying purpose of the reviewed systems' indicators. As in the process of categorizing indicators in primary categories, the choice of sub-categories and the placement of indicators within them were somewhat arbitrary. Many indicators could theoretically be grouped in several different ways and no methodological best practices could be found to clearly guide subcategory identification and use. Efforts were made to ensure that subcategories were established for any two or more indicators that sufficiently resembled each other and appeared to share a common orientation towards evaluating particular issues of concern. All indicators that did not sufficiently resemble other indicators were grouped into an "Other sub-category". Table 1 presents the results of this sub-categorization method for the international systems, and shows the most common indicator sub-categories found.

2.3. Rating of indicators based upon commonality and smart criteria

All sub-categories, excluding the "Other sub-category", as well as the specific indicators found to be common to more than three systems were combined to determine which indicators would be selected for inclusion in the final ELITE cities framework.

As an intermediate step, indicators and sub-categories were ranked for potential utility based on an indicator evaluation criteria called SMART (Doran, 1981). The SMART criteria is a system that has been used by business and political organizations to define contextually-appropriate goals and indicators by which to measure those goals. The system is based on a common problem discussed in agency theory: how to accurately transmit the desires of a principle in a way that can be easily and clearly understood and implemented by agents and evaluated by principles. Each letter of the acronym stays for a key characteristic that enhances the utility of indicators for guiding the activities of agents according to the intentions of principles. According to the SMART framework, indicators should be specific, measurable, achievable, relevant, and timely. The definitions of the SMART criteria as used for the selection of ELITE cities indicators are presented in Table 2.

The SMART framework was applied to the most common indicators in the following manner. Indicators were evaluated for each of the SMART criteria and given a score of 1–3, based on the extent to which they met each criterion's definition. A score of 1 was given to an indicator that was particularly weak in a criterion, and a score of 3 was given to an indicator that was judged as particularly strong in that criterion. A score of 2 was given to an indicator that did not appear to be strong or weak. The research team also applied a weighting scheme to the SMART criteria scoring that gave double weight to relevance and achievability criteria as compared to the specific and measurable criteria, and half weight to the timely criterion as compared to the specific and measurable criteria. This was done to optimize the utility of ELITE cities by prioritizing the use of already-available data and avoid the political pushback that might arise if indicators too often measured an issue outside the jurisdictional scope of city officials and managers. However, as indicated by the scoring system, poor performance in any SMART criterion did not necessarily determinative of whether the indicator was finally chosen, but rather offered a means of quickly evaluating the strengths and weaknesses of each indicator. The overall score of each indicator was summed and averaged by five for a final indicator SMART score.

The collected list of SMART-scored indicators and sub-categories was given to a panel of experts that included both six project researchers and two outside consultants who had experienced with city-level indicator system development. Two data sets were supplied to the panel along with each indicator: the indicators' SMART scores (both the consolidated and separate criteria scores) and the indicators' relative commonality in the reviewed international systems. The panel was instructed as to the meaning of each score. Panel discussions as to the merits of each indicator occurred over the course of two months in the summer of 2012. Discussions often centered on finding balance between two issues: (1) the objective of limiting the number of total indicators to a manageable set (a loose target of around 30 indicators total was established early in the selection process), and (2) comprehensively examining the most important issues in each primary category in terms of both international commonality and the link between the indicator and the environmental, social, and economic health of Chinese cities. Other data made available to

[1] The wide diversity of economic and social health issues prevented the further disaggregation of these categories.

Table 1
Commonality of indicator sub-categories.

Primary category	Sub-category	Example units of measurement	Commonality (proportion of systems with indicators placed in sub-category)
Energy and climate	Carbon intensity	CO_2e/unit GDP	63%
	Energy intensity	Primary energy use/unit GDP	50%
	Building energy use/Carbon	Number of green rated buildings per person (number per capita)	50%
	Renewable and clean energy	Proportion of primary energy from renewable sources (%)	45%
	Transport energy/Carbon	Energy use per vehicle mile traveled (J/VMT)	38%
	Energy and climate change policy	The existence of carbon emissions reduction targets (yes/no)	38%
	Split of total energy/Carbon within all sectors; energy security; industry energy/Carbon	Proportion of energy use in sectors (%); percentage of population with authorized electricity service (%)	<30%
Water quality, availability, and treatment	Water consumption intensity	liter/capita/day	56%
	Water quality	Proportion of water bodies over water quality limits (%)	44%
	Waste water treatment connection and rates	Proportion of homes connected to sanitary facilities (%)	44%
	Water availability by carrying capacity	Proportion of ground water extraction rate to refilling resources rate (%)	25%
	Access to water	Proportion of households with improved water source (%)	25%
	Other; water policy achievements	Marine trophic index (change in mean trophic level of fisheries landings); measure of a city's efforts to reduce pollution associated with inadequate sanitation (qualitative evaluation)	<30%
Air quality	PM10 concentrations	Annual daily PM10 concentrations in ug/m^2	44%
	NO_x concentrations and total emissions	Annual daily NO_x concentrations in ug/m^2	31%
	Other types of emissions; index of multiple air pollutant concentrations; exceedance of air quality benchmarks; SO_2 concentrations and emissions; O_3 concentrations and emissions; other	Toxicity equivalent tons released by nearby industrial firms (toxicity equivalents); ambient concentration of air pollutants in urban areas (ozone, Pm10, Pm2.5, SO_2, NO_2, and Pb, CO, NO, VOCs); number of days when pollution concentration exceeds guideline; POP. weighted SO_2 concentrations (ug/m^3)	<30%
Waste	Waste generation intensity	Total waste generated (kg/cap)	69%
	Waste treatment–recycling	Proportion of solid waste that is recycled (%)	56%
	Waste treatment–diversion from landfill; all treatment of total by proportion; waste treatment–landfill disposal; waste capture rates; other treatment; other waste indicators	Percentage of municipal solid waste diverted from the waste stream to be recycled (%); share of waste collected in the city and adequately disposed either in sanitary landfills, incineration sites or in regulated recycling facilities (%).	<30%
Transportation	Transportation facilities and infrastructure	Cars per capita	69%
	Modal sse	Proportion of commutes by non-automobile means (%)	69%
	Accessibility of transport options	Proportion of people living near public transit (%)	38%
	Policies; other; air transport.	Measure of a city's efforts to create a viable mass transport system as an alternative to private vehicles (qualitative); energy consumption by transport mode (% of total transport energy); commercial air connectivity (of flights)	<30%
Economic health	Employment	Unemployment rate (%)	50%
	Green or innovative sectors	Number of farmers markets per capita;	44%
	Cost of living	Proportion of income spent on housing (%)	44%
	Other	Local score on competitive index	38%
	GDP and income	GDP per capita	31%
	Debt, savings, and investment levels; government financing; businesses with environmental management systems; resource productivity.	Average savings rate (% of income); debt service ratio (debt service expenditures as a percent of a municipality's own-source revenue); % of organizations with registered environmental management system; resource productivity (GDP/annual quantity of raw materials extracted from the domestic territory of the focal economy, plus all physical imports minus exports)	<30%
Land use and urban form	Public green space	Proportion of city as dedicate green spaces	63%
	Population density	Number of people per m^2	56%
	Biodiversity	Number of bird specific present versus potential in region	38%
	Other; protected lands; built up area forestry; policies; smart growth index; ecological footprint; agricultural lands.	% of lands under legal conservation; soil sealing (m^2)/cap; proportion of county acreage in forest and farmland (%); does the city have a comprehensive urban biodiversity monitoring program?; acres of farmland in production by product in agricultural production districts (total)	<30%
Demographics and social health	Health	Average life expectancy (years)	50%
	Education	% of adults with a high school degree or equivalent (%)	50%
	Public, NGO, and academic participation	Voter participation rate (% of eligible)	44%
	Aesthetics	Adults who say they are satisfied with city environment (%)	38%
	City leadership in collaborative efforts	Existence of efforts by city to monitor environmental performance (qualitatively evaluated)	31%
	Risks and crime; equity; other; noise.	Number of homicides per 100,000 population; proportion of urban population living in slums (%); awareness raising and training to encourage the development and take-up of environmentally friendly technologies, particularly through training in industrial and business settings (qualitatively evaluated); share of population exposed to noise values of L (day) above 55 dB(A) (%)	<30%

the panel was an analysis of the commonality of indicators and sub-categories found within 11 city indicator systems in use in China. This commonality analysis was performed using similar methodologies as the review of the international systems and findings were introduced to the panel primarily to allow a determination of whether data collection and analysis capacity exists on the local level for certain indicators.

The panel experts were instructed to evaluate the scored and categorized indicators to determine a preliminary set of indicators based on their own expertise in each sector and available information regarding the challenges facing Chinese cities.

The panel prepared an initial set of 34 internally evaluated indicators for inclusion in the indicator system. Furthermore, the panel determined that four exogenous variables measuring economic structure and climate characteristics should also be reported for each city and included in the final ELITE cities tool to allow cities to be grouped by these potentially performance-determinative exogenous characteristics.

2.4. Weighting to prioritize certain sectors

The purpose of ELITE cities is to establish an overall score for cities based upon their consolidated performance across indicators. Unlike certification-oriented indicator systems such as the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) for Neighborhood Development community-scale certification system for green developments, Germany's Deutsche Gesellschaft für Nachhaltiges Bauen e.V. (DGNB) certification requirements for urban districts, Japan's Comprehensive Assessment System for Built Environment Efficiency (CASBEE's) city-level certification system, and the United Kingdom's BRE Environmental Assessment Method (BREEAM) building-level assessment methodology, ELITE cities does not allow participants to combine points from several optional efforts in each category. Rather, final ELITE cities scores are based on performance in all indicators, and does not allow for indicator replacement or substitution.

A city's total score will be calculated through a method by which benchmark-related scores in each indicator are consolidated into a score at the primary category level, with these primary category scores consolidated again at the overall level. Performance in each indicator is evaluated from 1 to 100, with 100 being the maximum possible points for each indicator and set by the chosen benchmark. Points are awarded within this range by one of two means. For indicators for which positive performance towards the benchmark is better (i.e., a higher absolute value is better), indicator score is determined by a simple division of the actual performance level by the benchmark level, to result in a percentage score. For indicators for which negative performance towards the benchmark is better (i.e., a lower absolute value is better), indicator score is determined by an inverse of the simple division formula. In the first iteration of ELITE cities, primary category level scores will be based on an unweighted average of indicator scores within each primary category, and overall score will be based on an unweighted addition of the primary category scores, for a total maximum of 800 points.

This scoring method in the first iteration of ELITE cities gives equal weight to each primary category in determining overall score, and equal weight to each indicator in determining each primary category score. However, as primary categories contain different numbers of indicators, indicators in different primary categories are assigned differing weights in determining a city's overall score. This methodology is the most common weighting scheme found among international indicator systems that resulted in the creation of a consolidated overall score, predominantly for the purposes of ranking cities against each other (Zhou and Williams, 2013).

2.5. Secondary characteristic categories to compare similar cities

Often the performance of cities will differ based on circumstances that are largely beyond the control of city managers and officials – these include both natural circumstances such as climate and resource limitations and anthropogenic circumstances such as the city's existing industrial structure. A relatively new concept in the use of city-level indicators is to subcategorize cities based on these exogenous characteristics to allow for a more detailed evaluation and to establish a fairer basis of comparison. Once a representative data sample is collected after an initial period of testing, ELITE cities allows for the evaluation of city performance in comparison to other cities that share similar certain exogenous characteristics. Although application of comparison will only begin in the second iteration of ELITE cities, the inclusion of these data input requirements in the first version may allow statistical evaluation to measure the extent to which economic structure plays a role in determining city performance.

The subgroupings included in this first version of ELITE cities regard economic structure and climate. Economic structure is quantified by the proportion of primary, secondary, and tertiary industrial sectors to the city's overall annual gross domestic product (GDP). Heavy industrial activity is a primary source of environmental harms and energy consumption in China and the economic dominance of any sector is assumed to have other political, sociological, and economic impacts.

Climate characteristics are evaluated in two ways: by grouping cities into one of five climate zones established by national building energy codes, and by indicating the relative scarcity of water resources within the province in which the city resides. The nationally applicable climate typology designated for each prefecture-level cities (PLC) has been indexed in the ELITE Cities database so as to load the city's climate type when users choose the city of application. Cities are also automatically indexed by the scarcity of water at the provincial level. This metric, also used in the study by Esty et al. (2011), is based on the relationship between a province's annual water consumption to annually available water resources. Both climate-measuring secondary characteristics are included because both thermal energy and water availability may limit or exaggerate performance in core indicators enough to cause variation in overall ELITE cities scoring. After initial data collection efforts, studies will be undertaken to determine which if any of these secondary variables have a statically valid relationship with performance in any one indicator and such findings may help improve ELITE cities in future iterations.

When fully implemented, ranking cities according to their performance among peer groups will not replace the overall scoring system, but rather is intended to be an additional means of analyzing a city's performance. By establishing peer groups, it is hoped that the ranking system will allow for an improved means of indicating best practices and highlight improvements in city performance that may happen at different paces, but are nevertheless significant in their own right.

2.6. Consultation with Chinese experts and refining of indicators

The internally drafted proposed indicators and four secondary characteristics were presented to partners at the Chinese Society of Urban Studies (CSUS) to receive their comments, thoughts and suggestions for revision. CSUS is a think tank under MOHURD in charge of implementing low-carbon eco-cities and is the counter party of the U.S. Department of Energy (DOE) for the Strategic Economic Dialogue Framework. These comments were received

Table 2
SMART criteria definitions used in ELITE cities development.

Criteria	Definition
Specific	Indicators measure what they claim to measure, without the introduction of biases due to vague or culturally-sensitive word choices.
Measurable	Clear definition is given for the scope and boundaries of the numerator, the denominator, the calculation methodology and the measurement units. The same data collection and evaluation methodology can be applied by all measurement subjects, and the data may be logically compared between time periods and between locations. There are no social, political nor cultural restrictions on collecting and publishing the data.
Achievable	Data required for the indicator already exists, can be derived from existing data or can be collected with relatively low costs. Collection of data at the local level is feasible given the institutional capacity and bureaucratic limitations that exist at the local level.
Relevant	Indicator provides information that can be acted on by local government officials and city managers acting within the normal limits of their jobs. The indicator responds to efforts by city managers and officials.
Timely	Indicator is based upon data that is or can be regularly collected at a constant interval in all evaluated locations. The indicator can show sufficiently visible changes at the time scale at which data is collected and evaluated.

Note: there is some controversy about the precise definition of each of the SMART criteria. This table gives the operational definitions for the SMART criteria that were applied in the ELITE cities project.

and responded to by the research team; although the majority of proposed indicators remained in subsequent iterations, the scope of several indicators' denominators were narrowed based on CSUS concerns about the availability of data and the scope of local leaders' policy-making abilities. A few indicators were completely eliminated and replaced with indicators suggested by experts at CSUS.

2.7. Benchmarks to evaluate performance

Once the final list of indicators was assembled, the research team set about searching for benchmarks by which to evaluate performance in each indicator. Data were gathered for each indicator from seven types of sources: (1) Chinese official national targets contained in the 12th Five Year Plan; (2) other national targets from long range planning documents; (3) targets and goals established by individual Chinese cities identified as progressive leaders; (4) recent national averages from Chinese statistical yearbooks; (5) best practices as established by international organizations; (6) best practices from the top-performing cities in the evaluated international indicator systems; and (7) performance levels of cities identified as leading cities by international experts. Best efforts were made to find relevant data for each chosen indicator in each type of benchmark source; however, in the majority of cases benchmarks could not be found for several source types. When appropriate benchmarks could not be found in the above categories, efforts were made to conduct sweeping internet searches to find data sources that would establish a sufficiently large population of potential benchmarks from which final benchmarks could be derived.

Potential benchmarks for each category were analyzed based on several criteria; the most important of which was a certain relevance to local circumstances. In the case that benchmarks were found from a wide variety of sources, benchmark selection preference was given to China's national goals and to well-defined international best practices suitable to the Chinese context. National goals were assumed to be relevant to every location. Benchmarks for which international best practices could be identified were analyzed according to whether international best practices were applicable to the Chinese context, based upon average China's current performance levels, national goals, and city-level goals. The research team determined that in many cases international best practices were inapplicable to the Chinese context because average Chinese city practices were already superior to the levels found for international best practice cities. In this case, the international best practices were discarded and preference was given to either Chinese national goals or an adjustment of Chinese national goals based upon an assessment of what was feasibly attainable by demonstrably well-performing of Chinese cities.

The benchmarks have been established as the maximum feasible performance levels for each indicator, and therefore, the maximum points available for any indicator is set at the level of the chosen benchmarks. This approach required the research team to balance two principles when setting the benchmarks. On the one hand, benchmarks have to sufficiently high as to preclude devaluing the efforts of strongly performing cities. If benchmarks were set too low, high-performing cities might be given the same number of points as cities that were performing below them (i.e., all cities attaining a benchmark would get full points for that category). A benchmark that was set too low could therefore limit the incentive of high-performing cities to strive to further improve performance. On the other hand, if benchmarks were set too high, a city's performance levels could be observed to clump at some much lower point and it would become difficult to differentiate superior city performance from average city performance.

In a few cases, neither an international best practice nor a domestic national or city-level goal could be found for a chosen indicator. In such cases, expert judgment was applied. In a few such cases, the scope of the indicator numerator or denominator was narrowed so as to confine the indicator to a scope for which appropriate benchmarks could be found. The details of how benchmarks were chosen and their origin are given below, in Section 3.

3. Results

3.1. Final indicator system and selected benchmarks

ELITE cities calls for measuring progress through 33 indicators chosen to represent priority issues within these eight primary categories.

Table 3 summarizes the ELITE cities indicators, their scope, units of measurement, benchmark performance levels, and data source.

3.2. Application boundary: China's prefectural level cities and above

China has 663 official cities, including four province-level municipalities, 283 PLCs and 370 county-level cities (CLCs). The four provincial-level municipalities – Beijing, Shanghai, Tianjin, and Chongqing – are given status and administrative powers nearly equal to provinces. The PLCs are generally smaller in population size than provincial-level cities, and they report to provincial governments. The CLCs are county level administrative seats that meet certain benchmarks for a statutory city and report to PLCs. A key distinguishing factor between PLCs and CLCs is that

Table 3
Final ELITE cities indicators and benchmarks.

Primary category	Indicator name	Indicator scope	Units	Benchmark	Source
Energy/ Climate	CO_2 intensity	Total carbon dioxide (CO_2) emissions per capita	tons/capita year	2.19 tons/cap year	UN Habitat State of the World Cities 2008/2009, Part 3, p. 135; Oslo is picked as the benchmark.
	Residential building energy intensity	All residential building average energy intensity per square meter building space	kilowatt-hours per square meter per year (kWh/m^2 year)	Cold climate: 88 kWh/m^2 year severe cold climate: 132.7 kWh/m^2 year hot summer cold winter climate: 69.7 kWh/m^2 year hot summer warm winter climate: 54.7 kWh/m^2 year moderate: 50 kWh/m^2 year	Jiang Yi, China Building Energy Efficiency Develepment Report.
	Public building electricity intensity	Public building average electricity intensity per square meter	kWh/m^2 year	70 kWh/m^2 year	Jiang Yi, China Building Energy Efficiency Development Report. Shenzhen data is set as the benchmark.
	Share of renewable electricity	Renewable energy (excluding nuclear) as a share of total city purchased electricity	% of total electricity purchased	20%	National 12th Five-Year Plan for New Energy Development and Caofeidian Eco-city Indicator System's target.
Water	Municipal water consumption	Municipal water consumption per capita	liter/capita day	52.1 l/cap day	Hamburg (2009).
	Industrial water consumption	Industrial water consumption per industrial GDP	liter/annual 10,000 Renminbi (RMB)	80.5 l/10,000 RMB	World Bank, TRACE tool.
	Wastewater treatment rate	Percentage of wastewater receiving at least primary treatment	% of total wastewater	100%	LBNL expert team decision.
	Drinking water quality	Percentage of total drinking water meeting Grade III or above	% of total drinking water	100%	LBNL expert team decision.
	Recycled water use	Percentage of annual municipal water use sourced from water reclamation	% of total municipal water	30%	MOHURD eco-garden city program standard.
	Energy intensity of drinking water	Energy intensity of drinking water	Kilowatt-hours per liter (kWh/l)	0.10 kWh/l	World Bank, TRACE tool. Sydney (2009).
Air	PM_{10} concentrations	Daily average PM_{10} concentration	Micrograms per cubic meter (g/m^3)	20 μg/m^3	WHO (2006). 24-h mean.
	NO_x concentrations	Daily average NO_x concentration	g/m^3	40 μg/m^3	WHO (2006). 24-h mean.
	SO_2 concentrations	Daily average SO_2 concentration	g/m^3	20 μg/m^3	WHO (2006). 24-h mean.
	Air pollution days	Proportion of days per year that air quality meets Level II standard ("blue sky" threshold)	% of total days per year	100%	LBNL expert team decision.
Waste	Municipal waste intensity	kilograms (kg) of total collected MSW per capita	kg/capita/year	0.29 kg/cap/year	Shanghai target.
	Municipal waste treatment rate	Percentage of collected MSW receiving "harmless" treatment	% of total collected MSW	100%	LBNL expert team decision.
	Industrial recycling rate	Comprehensive industrial waste utilization rate	% of industrial solid wastes	100%	LBNL expert team decision.
Mobility	Public transportation network penetration	Public transport penetration rate as a proportion of total city area	kilometers per square kilometer (km/km^2)	4 km/km^2	Upper end of national target: code for transport planning on urban road. (GB 50,220-95): 3.2.2
	Public transportation share of trips	Share of public transportation trips in all trips	% of all trips/year	60%	12th Five-Year Comprehensive Plan for Transport System, national target city with 10 million population.
	Access to public transportation	Percentage of built area within 500 meters of public transit	% of built area	90%	MOHURD, Public Transport Demonstration Project, html
	Municipal fleet improvement	Proportion of energy-efficient and new-fuel vehicles (electric, hybrid, biofuel, <1.6 l-and-below cars) in the city vehicle fleet and taxi fleet	% of total vehicles	100%	LBNL expert team decision.
Economic health	Employment	Registered unemployment rate	% of eligible adults	3%	Chinese City Statistic Yearbook, Chongqing 12th Five-Year Plan, 2015 target.
	Environmental protection spending ratio	Ratio of environmental protection spending to GDP	% of annual GDP	3%	National 12th Five-Year Plan for Environmental Protection.
	R&D investment ratio	Ratio of R&D spending to GDP	% of annual GDP	5.5%	Beijing 12th Five-Year Plan

Table 3 (*Continued*)

Primary category	Indicator name	Indicator scope	Units	Benchmark	Source
	Organic certification of agricultural land	Percentage of total agricultural land area certified as organic	% of agricultural land	1%	FiBL-IFOAM survey.
Land use	Green space intensity	Average per capita public urban boundary inclusive green space	m^2 of green space/capita	100 m^2/capita	EIU Asia, Hong Kong average.
	Share of mixed-use zoning	Percent of total city land zoned for mixed use	% of total area	13.3%	Manhattan of New York is reported as 13.3%
	Population density	Land use per capita	m^2 per capita	100	Land and population data from China City Statistical Yearbook.
Social health	Health care availability	Health care practitioners per 1000 persons	Health care practitioners per 1,000 persons	14	Beijing 12th Five-Year Plan; China Statistic Yearbook 2011.
	Share of workers from higher education	Percent of employed population with university degree	% of employed persons	45%	U.S. ACS 2010, San Jose as benchmark.
	Internet connectivity	Percent of households with an internet connection	% of households	100%	LBNL expert team decision.
	Eco-city planning completeness	Eco-city planning and policy completeness	100 points – 10 policies with full points awarded for achieving the policy and 0 points for not achieving the policy*.	100%	LBNL expert team decision.
	Affordable housing availability	Percentage of total housing designated as "affordable"	% of total housing	20%	National target as 12th Five-Year Plan.

Note: PM_{10} = particulate matter < 10 μm in diameter; NO_x = nitrogen oxides; SO_2 = sulfur dioxide.

* Policies for the eco-city planning completeness indicator: has the city conducted a carbon inventory? has the city undertaken energy audits of its own operations, including city service entities and public buildings? has the city conducted an audit of water consumption in the city and losses in distribution systems? has the city conducted an audit of the contents of its municipal waste stream? has the city conducted an audit of mobility patterns of its residents? does the city regularly survey residents regarding their perspectives of city environmental quality? has the city established a low-carbon development plan? does the city have a single online platform to inform citizens of progress towards low-carbon eco-city goals? does the city government have a department that manages and/or tracks all low-carbon development activities by the city's government departments? does the city have a low-carbon eco-city district or industrial park demonstration project?

city sub-districts are permitted in PLCs, creating a two-tiered administrative structure; whereas, CLCs are single-tier administrations without sub-districts.

The international indicator systems reviewed in preparation for this project all limited the scope of their application to a select subset of the total cities in a jurisdiction, although based upon different methods. These systems variously selected cities for evaluation based on population size, political designation, and expert-based evaluation of features of the cities' economic, political and cultural importance, generally indicating that only governments above a threshold should be evaluated for eco-city characteristics. Due to the importance of PLCs in the national economy and regional political structures, and the relative lack of independent policy-making power of CLCs, the scope of the application of ELITE cities was limited to Chinese mainland cities of PLC designation or higher.

4. Conclusion

China is pursuing the development of low-carbon eco-cities with the purpose of providing urbanites with a clean environment, a growing economy, and a society that promotes harmonious citizen interactions, while simultaneously limiting carbon dioxide and other GHG emissions and other environmental damage and liabilities. ELITE cities, developed by the China Energy Group at LBNL, measures progress through 33 key indicators chosen to represent priority issues within eight primary categories. Those indicators were selected based on the commonality of their use worldwide and SMART criteria by extensive review of 16 international indicator systems and 11 domestic indicator systems. Benchmark and weighting mechanisms from world and national best practices are applied to the key indicators. An excel-based tool was then developed to package the indicators, benchmarks, explanation of indicators, function and data sources instruction so the tool is intuitive and simple to use. The ELITE cities tool as explained in this paper, could be a useful and effective tool for local city government in defining and evaluating the status of a low-carbon eco-cities and assessing the progress of developing a low-carbon eco-city. ELITE cities can also be used by higher governmental levels – for example, the central government – to assess the performance of local cities in developing low-carbon eco-cities with data input from either local governments or centralized data collection processes. Due to the relative newness and dynamic evolution of this field in urban development, no city in the world has been proven to achieve either a locally defined or globally-defined standard of sustainability and no standardized threshold values exist to determine whether a city is "ecological" or "low-carbon". The indicators and related benchmarks for assessment might change over time and need to be updated per environmental changes. In the next research phase, we will pick a few representative cities for case studies, to test and improve the indicator system and update the benchmarks accordingly.

Acknowledgments

This work was supported through the U.S. Department of Energy under Contract No. DE-AC02-05CH11231. We appreciate the comments from the anonymous reviewer. The authors would like to thank Lixuan Hong, Qibo Liu, Brian Heimberg and Warren Karlenzig for their input and suggestions.

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