Ecological Indicators 128 (2021) 107828

Contents lists available at ScienceDirect

Ecological Indicators

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

MBO based indicator-setting method for promoting low carbon city practice

Xiaoyun Du [a,b], Liyin Shen [a,b,*], Siu Wai Wong [c], Conghui Meng [a,b], Guangyu Cheng [a,b], Fuyi Yao [a]

[a] School of Management Science and Real Estate, Chongqing University, China
[b] International Research Center for Sustainable Built Environment, Chongqing University, China
[c] Department of Building and Real Estate, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, China

ARTICLE INFO

Keywords:
Low carbon city (LCC)
LCC objective
Tailor-made indicator
Management by Objectives (MBO)

ABSTRACT

Cities with different development backgrounds and characteristics will set different objectives for promoting low carbon city practice, including overall, dimensional, and executable objectives. Therefore, a method is needed to ensure that the selected indicators are tailor-made and can correspond to objectives. The existing methods for selecting LCC indicators are not objective-based. This paper introduces an innovative method for setting LCC indicators by using the Management by Objectives (MBO) method to enable the achievement of LCC objectives. Two case cities are used to demonstrate the application of the MBO-based indicator setting method. The main conclusion can be drawn from this study as follows. Firstly, different cities should apply different indicators to guide their LCC practice as they have different backgrounds. Secondly, the MBO method can help different cities to set tailor-made indicators to guide their LCC practice towards their LCC objectives. It is emphasized that indicators applicable to different cities should not be selected discriminately. Thirdly, there are three basic procedures in applying the MBO based indicator setting method, namely, identification of the overall LCC objectives, decomposition of the overall LCC objectives into the dimensional and executable LCC objectives, and selection of indicators for evaluating executable LCC objectives. The application of the MBO based indicator setting method can help the cities choose a set of indicators most suitable to local conditions to guide the LCC practice towards achieving their LCC objective defined locally.

1. Introduction

Climate change caused by increasing greenhouse gas (GHG) emissions has become one of the biggest challenges to humankind. Carbon dioxide (CO_2) accounts for the biggest proportion of GHGs and is the principal GHG causing climate change (Shi et al., 2017). Thus, carbon emission reduction has become a top agenda for all countries throughout the world (Shen et al., 2018b). Cities account for up to 75% of CO_2 emissions, and this proportion figure is expected to grow further with increasing urbanization (IPCC, 2014; Lee & Erickson, 2017). Therefore, cities are the major stakeholders assuming the responsibility of emission reduction. In line with this, low carbon city (LCC) practice becomes a core strategy to reduce carbon emissions. It has been noted that more and more cities have positioned LCC practice as a top priority strategy in their development blueprints (Tan et al., 2017). For example, according to Su et al. (2013), 1050 cities in the United States, 40 cities in India, 100 cities in China, and 83 cities in Japan have set specific objectives in practicing LCC practice. 40 mega cities from various countries formed the Cities Climate Leadership Group (C40) in 2006 in response to the appeal of carbon emission reduction, and these cities have their specific emission reduction goals. Table 1 shows the emission reduction goals set by several typical mega cities (Tan et al., 2017). A number of countries have also defined specific emission reduction goals at the national level. For example, the Chinese government announced in 2016 that its carbon emissions will be reduced by 18% from 2015 to 2020 (NDRC, 2016).

In order to accomplish emission reduction goals at either the national or city level, objectives need to be specified at different dimensions for allowing effective implementations or executable in practice. In other words, emission reduction goals have to be divided into various dimensional objectives, which are further decomposed into executable or actionable objectives. In general, carbon emission reduction goals are attributed to the dimensions of optimizing energy structure, reforming industrial structure, energy-saving, and so on. Each dimension will be further specified by a number of executable objectives. For example, the

* Corresponding author at: International Research Center for Sustainable Built Environment, Chongqing University, China.
E-mail address: shenliyincqu@163.com (L. Shen).

https://doi.org/10.1016/j.ecolind.2021.107828
Received 19 June 2020; Received in revised form 20 April 2021; Accepted 23 May 2021
Available online 26 May 2021

Table 1
Emission reduction goals set in typical mega cities.

City	Emission reduction goals
New York North	To reduce GHG emissions by 30% for the period from 1990 to 2030
Chicago	To reduce GHG emissions by 25% from 1990 to 2020, and by 80% by the year 2050
Copenhagen	To reduce GHG emission by 20% from 2005 to 2015
London	To reduce 60% GHG emission from 1990 to 2025
Rotterdam	To reduce 50% GHG emissions from 2020 to 2020
Seoul	To reduce GHG emissions by 40% from 1990 to 2030
Tokyo	To reduce GHG emissions by 25% from 2000 to 2020
Sydney	To reduce GHG emissions by 20% from 2006 to 2012, and 70% by the year 2030

Source: (Tan et al., 2017).

dimensional emission reduction objective of optimizing energy structure can be further decomposed to the following executable objectives: development and promotion of non-fossil energy, increasing of natural gas utilization, adjusting and optimizing thermal power projects, and upgrading of coal-fired boilers(The Development and Reform Commission of Shenzhen Municipality, 2013). However, it is important to appreciate that dimensional or executable emission reduction objectives will be different between different countries and cities because of the different backgrounds that individual cities have. For example, economically developed countries will give more weight to the development of technology when promoting LCC practice, as less developed countries will pay more attention to the development of the economy (Shuai et al., 2017). A North city in China will give more weight on optimizing thermal power projects when practicing LCC since they have more coal, and a South city will pay more weight on the optimizing hydroelectric power projects since they have plenty of water resources (Zhou et al., 2019).

It can be seen that achievement of emission reduction goals depends on the completion of executable objectives. Indicators are recognized as analytical and interpretive tools and solid basis for policy-making and communication in a variety of ways, thus proper indicator-setting is very important (Singh et al., 2012). As appreciated in previous studies, suitable assessment indicators are not only useful for measuring progress but also for discovering problems and identifying management strategies for corrections (Reed et al., 2006; Zhou et al., 2015a). Therefore, it is essential that executable emission reduction objectives can be completed successfully, and this can only be done by employing a set of indicators to help evaluate dynamically whether the emission reduction performance in the process of LCC practice is towards the successful completion of executable objectives. These indicators should be set in a way that can indicate the performance level referring to executable objectives. Executable objectives can be failed if the assessment indicators are not set in association with the objectives.

In fact, LCC has been promoted increasingly since early 2000 globally. However, it appears that the efficiency of LCC practice is limited. For example, global carbon emissions reached 36.14 billion tons in 2014, which has tripled compared to that in 1960 (Wu et al., 2019). It is widely appreciated that carbon emissions are still stimulating the trend of global warming, which threatens the ecosystem and human wellbeing (Shi et al., 2017, Wu et al., 2019). According to Song et al. (2018), the Chinese government has introduced a number of pilot LCC programs since 2010, but these pilot cities have not achieved their preset objectives. This is mainly because the indicators for evaluating the LCC performance are not combined with the objectives. For example, the dimensional objective of carbon dioxide emissions of Beijing was specified as adjusting the industrial structure, increasing carbon sinks, and optimizing the energy structure (Shen et al., 2018a). However, the indicators for measuring the LCC performance of Beijing were recorded as the dimension of low carbon production, low carbon consumption, low carbon environment, and low carbon urban planning, which shows a significant difference from what was specified in the objective(Yang and Li, 2012). Although these are various indicator systems introduced for the evaluation of LCC practice, it appears that many of these indicators are general and often not associated with the executable objectives defined by individual cities. Different cities are in different development stages and have different backgrounds, thus the executable LCC objectives they defined are different.

It is therefore important to introduce a method that can ensure the indicators set have a close association with executable LCC objectives specified in a concerned city. Without considering this association, the LCC performance cannot be assessed properly. The rest of this paper is thus organized as follows. Section 2 presents literature review. Section 3 describes the research method. Section 4 demonstrates the MBO based LCC indicator setting method. Section 5 shows the application of the proposed method. And Section 6 presents the discussion and is followed by section 7 conclusion.

2. Literature review

A number of studies have investigated the selection of LCC assessment indicators. Most of the previous indicators are not objective-based. For example, Sharma and Balachandra (2015) evaluated the low carbon performance of the electricity system in India by using a hierarchical indicator framework which includes the indicators of the age of villages electrified, urban household electricity access, and rural household electricity access. These are no indicators related to LCC objectives in this research. A low-carbon eco-city evaluation tool (ELITE) was developed by Lawrence Berkeley National Laboratory to evaluate cities low carbon performance within eight dimensions, including energy and climate, water, air, mobility, land use, waste, economy, and social health (Zhou et al., 2015c). However, the dimensions in this study are not closely related to the objectives of LCC practice. Indicators adopted in ELITE include PM10 concentrations, NOx concentrations, air quality, and others are not related to LCC objectives. Some research employed several indicators to reflect the overall LCC objective. For example, Dennis (2009) developed an LCC index system for evaluating the LCC performance in three areas, including policy-making, emission, and investment. Some of the indicators in this study can reflect the overall objective for carbon reduction, but most of the indicators such as unemployment rate, number of farmers markets per capita, and cost of living proportion of income spent on housing are not objective-based. Some of the previous studies have mentioned a certain LCC dimensional objective (Tan et al., 2017; Price et al., 2013). For instance, in investigating carbon emission performance in 10 pilot LCC cities in the world, Tan et al. (2017) presented an LCC indicator framework composing of seven dimensions, including city economic, energy pattern, social and living, carbon and environment, urban mobility, waste, and water. The indicators employed in their study are mainly for assessing the performance of the energy pattern, which is a typical dimensional objective for LCC practice. But most of the indicators in this study such as daily sulfur dioxide levels, solid waste generation per capita, the share of waste collected and adequately disposed of are not closely related to LCC objectives. Price et al. (2013) presented LCC performance assessment indicators across five dimensions of industry, residential, commercial, transport, and electric power, and the typical indicators included in their study are primary energy consumption/GDP, residential final energy/capita, and final energy consumption/GDP, commercial final energy/tertiary sector employees, end-use CD2/GDP, industrial final energy/industry GDP and others. Most of the mentioned indicators can reflect the dimensional objective of energy effectiveness.

Whilst there are still other indicator systems introduced in existing studies for assessing LCC performance, the consistency between these indicator systems demonstrates the fragmentation in applying LCC performance assessment indicators, which affect the application of these research results. As argued in the study by Fu et al. (2010), the fragmentation of LCC assessment indicators is mainly due to the lack of principle or methodology to supervise the way of indicator-setting. In line with this argument, Fu et al. (2010) suggested that LCC assessment indicators should be selected by applying the principle of sustainable development, thus the assessment indicators are classified in the social, economic, and environmental three dimensions. According to this principle, they selected a number of LCC indicators, as shown in Table 2.

In another study by Zhou et al. (2015a), the DPSIR method is used in formulating an LCC indicator framework which composes of five dimensions, namely, dynamics, pressure on the environment, state, impacts, and responses. Lin et al. (2014) adopted a decomposed method for establishing LCC indicators for evaluating carbon intensity reduction performance, in which the indicators are grouped into four dimensions, namely, energy, waste, agriculture and carbon intensity. However, these methods adopted for setting LCC indicators do not take into account the LCC objectives specified in different cities. In other words, the indicators established by using existing methods are not associated with LCC objectives.

The above discussions demonstrate that although various LCC assessment indicators have been investigated and proposed in previous studies, they are either fragmental or not objective-focused. There is no existing study proposing LCC indicators from the perspective of in particular executable objectives. The missing of an objective perspective in setting LCC indicators is considered one of the major reasons for being unable to achieve emission reduction goals. In summary, LCC assessment indicators set by using the methods proposed in the existing studies cannot reflect the requirement of LCC objectives, thus these indicators are of limited helpfulness for guiding LCC practice. Therefore, this paper aims to introduce a new indicator-setting method based on the principle of Management by Objectives (MBO), which enables the indicators selected to have a close association with LCC objectives. Consequently, LCC practice can be guided by these MBO based indicators towards the achievements of the specified LCC objectives.

3. Research method

The principle of Management by Objective (MBO) is applied for setting a list of unique and synthetic LCC indicators that are associated closely with LCC objectives. The method of MBO was originally proposed by Drucker in 1954, and the key to this method is to finish a planned task by controlling objectives (Rodgers and Hunter, 1992). The general principle of applying MBO methodology includes three procedures, namely, objective identification, task decomposition, and task quantification (Nayab, 2009). MBO is appreciated as an effective, systematic, and results-oriented method. The major three advantages of the MBO method are widely appreciated: firstly, this approach can overcome the disadvantages of conventional management focusing on behavior with less attention to objectives and planning. Secondly, the MBO method is more systematic and integrated with a hierarchy structure between the overall objectives, dimensional objectives, and executable objectives. The overall objective can be achieved by completing the executable objective. Thirdly, the MBO method emphasizes the importance of objective results, and the identification of the deviation between the target and the reality, thus corrections can be taken in time through using quantifiable standards. In other words, managers can take actions to modify the deviations and further ascertain the effects of objectives. Due to these advantages, the application of the MBO method has been extended from performance measurement to strategic planning and managerial control over the work of employees in an enterprise (Erdogan et al., 2001). And this method is also considered applicable in setting various assessment indicators. For example, Zhou et al. (2015b) employed the principle of MBO to develop an index framework for assessing urbanization performance and argued that the identified indicators can be more forward-looking and consistent with the overall objective of the evaluation. They further pointed out that the conventional indicator setting method often results in the irrelevance of the indicates with assessment objectives (Zhou et al., 2015b).

By appreciating the advantages of the MBO principle, this study is to employ this principle to develop MBO based indicator setting method for selecting LCC assessment indicators. In line with the MBO principle, three procedures need to be conducted: (1) to identify LCC's overall objective, (2) to decompose the overall objective into dimensional and executable objectives, and (3) to select indicators for evaluating executable objectives. Three research procedures are shown in Fig. 1.

The framework in Fig. 1 suggests that the identification of the overall objective will be conducted through literature review. The result of decomposition of the overall objective into the dimensional objective and executable objective will be conducted by content analysis. The selection of indicators which can reflect the performance of executable objectives will be conducted by literature review and expert interview.

4. Development of MBO based LCC indicator setting method

4.1. The identification of overall LCC objectives

According to the research framework in Fig. 1, overall LCC objectives will be identified through a literature review. Objectives provide common guidance for all decisions in a company and form the basis for other detailed goals appropriate for specific decisions (Keeney, 1994). And these objectives are commonly from various official LCC plans enacted by city governments. For example, the Shenzhen government defined its overall LCC carbon dioxide emissions of 10,000 yuan GDP as 0.18 tons in 2020 (The Development and Reform Commission of Shenzhen Municipality, 2013). Therefore, this paper will identify the LCC objectives through reviewing relevant policies and government reports. There can be various forms for defining overall LCC objectives. For example, total carbon emissions, carbon intensity, and carbon emissions per capita, carbon dioxide emissions of 10,000 yuan GDP, the turning point of total low carbon emission (TP_{tc}). However, it is appreciated that TP is the most common overall objective used by cities.

Shen et al (2018a) also pointed out that the overall LCC objective is to control carbon emissions volume in order to reach TP_{tc} as soon as possible. In fact, many Chinese cities, particularly, these low carbon pilot cities have defined their overall LCC objectives in their LCC development plans, which can be accessed from the Legal Database of Peking University (LDPU) and the official website of these pilot cities. LDPU is the largest law database for retrieving official documents in China. As a result, 38 policy documents have been collected, coded as $P_1…P_{38}$, as shown in Appendix I. According to the documents in Appendix I, the overall LCC objectives TP_{tc} between these low carbon pilot cities can be identified, as demonstrated in Table 3.

According to Table 3, 71 out of 81 low carbon pilot cities in China have set specific overall LCC objectives in their policy documents. But these specific objectives are different between cities, due to their

Table 2
The LCC indicators selected by the principle of sustainable development.

Dimension	Indicators
D_1- social	The proportion of low carbon consumption expenditure of urban residents, the number of jobs provided by unit carbon emissions.
D_2-economic	GDP carbon intensity, per capita carbon emission level.
D_3 -environmental	Forest coverage rate, COD emission intensity, S02 emission intensity

Reference: Fu et al., 2010.

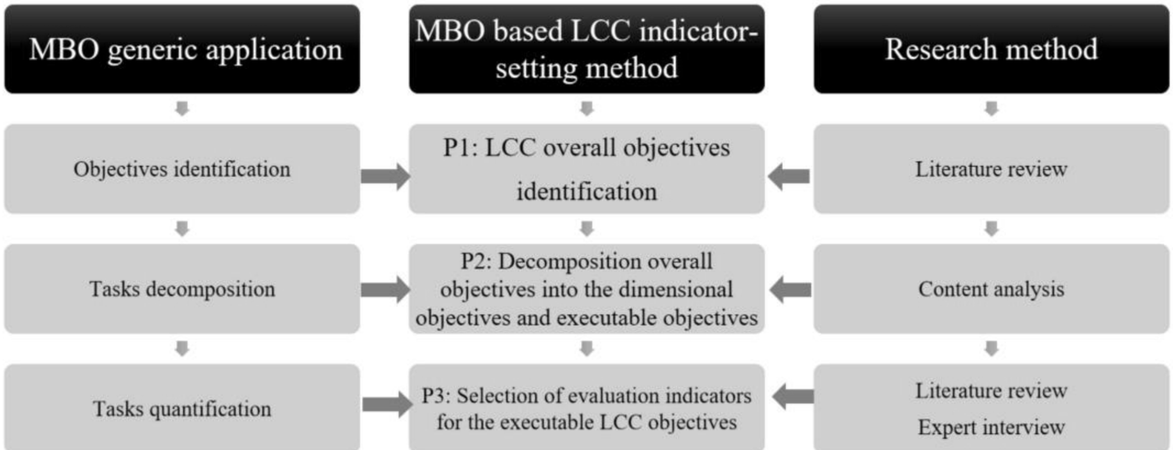

Fig. 1. The framework of developing MBO based LCC indicator-setting method.

Table 3
The overall objectives TP_{tc} between low carbon pilot cities in China.

City	TP_{tc}	City	TP_{tc}	City	TP_{tc}
Tianjin	2025	Wuhan	2020	Fub	2026
Chongqing	2030	Guangzhou	2020	Jinan	2025
Shenzhen	2022	Guilin	2030	Yantai	2017
Xiamen	—	Guangyuan	2030	Weifang	2025
Hangzhou	—	Zunyi	2030	Jincheng	2023
Shanghai	2020	Changji	2025	Jilin	2025
Xuancheng	2025	Yining	2021	Daxinganling	—
Sanming	2027	Hetian	2025	Suzhou	2020
Gongqingcheng	2027	Jinchang	2025	Huaian	2025
Jian	2023	Wuhai	2025	Zhongshan	2023–2025
Shijiazhuang	—	Shenyang	2027	Liuzhou	2026
Qinhuangdao	2020	Dalian	2025	Sanya	2025
Beijing	2020	Chaoyang	2025	Ankang	2028
Hulunbeier	—	Xunke County	2024	Chengdu	2025
Changsha	2025	Nanjing	2022	Jingdezhen	—
Zhuzhou	2025	Changzhou	2023	Ganzhou	2023
Xiangtan	2028	Jiaxing	2023	Qingdao	2020
Chenzhou	2027	Jinhua	2020	Jiyuan	2019
Zhenjiang	2020	Quzhou	2022	Lanzhou	2025
Ningbo	2015	Hefei	2024	Dunhuang	2019
Wenzhou	2019	Huaibei	2025	Xining	2025
Chizhou	2030	Huangshan	2020	Yinchuan	2025
Nanping	2020	Luan	2030	Wuzhong	2020
Yuxi	2028	Nanchang	—	Kunming	—
Urumqi	2030	Guiyang	2025	Yanan	2029
Lasa	2024	Baoding	—	Wada First Division Alar	2025
Changyang Tujia Autonomous County	2023	Qiongzhong Li and Miao Autonomous County	2025	Simao District, Pu'er City	2025

Source: The Legal Database of Peking University, official websites of the low carbon pilot cites.
Note: "—" indicates that the corresponding pilot city has not indicated their TP_{tc}.

different local conditions. Differences in setting overall LCC objectives between cities are spanning from 2015 for the city of Ningbo to 2030 for the city of Urumqi. Most of these cities have their TPtc target for the year after 2025. The latest peak year for LCC overall objectives is 2030 by Urumqi, which is also the national target committed by the central government in the Paris Climate Change Conference (UNFCCC, 2015).

4.2. Decomposition of LCC overall objectives into dimensional and executable objectives

4.2.1. Dimensional objectives

According to the principle of MBO, the overall LCC objectives have to be decomposed into dimensional and executable objectives to ensure that overall objectives can be achieved. The overall LCC objective, namely, the TPtc target will be achieved through different dimensional objectives (Chang et al., 2019; Mi et al., 2015). Different cities have defined various dimensional and executable objectives in order to achieve their overall LCC objectives in practice. For example, Chongqing has defined dimensional objectives, including to accelerate the adjustment of industrial structure and build a low-carbon industrial system, to develop low-carbon energy systems, to promote resource conservation, and reduce energy, to increase carbon sinks. For another example, Shenzhen has defined the following dimensional objectives for implementing its overall LCC objectives, adjustment industrial structure, optimization of the energy structure, energy conservation and consumption reduction, increasing carbon sink capacity, implementing low-carbon projects. All the pilot cities in China have defined their dimensional and executable low carbon objectives in their LCC development plans. The method of content analysis is used to appreciate the dimension objectives and the executable LCC objectives defined in these LCC development plans. The content analysis method is appreciated as an effective method to analyze the contents of newspapers, political reports, intelligence, and folklore (Shen et al., 2018a). It has been continuously promoted, particularly in sociology disciplines. Therefore, content analysis will be used to identify dimensional objectives for LCC practice.

According to the content analysis method, the documents related to LCC will be collected firstly, which have had been collected in AppendixI, namely, the 38 documents. Secondly, 875 policy analysis units are identified through the analysis of 38 documents. Thirdly, the preliminary dimension objectives for each policy analysis unit are identified. Finally, these preliminary dimension objectives with same semantics are further merged. For example, the following preliminary dimension objectives "promoting low carbon industry", "accelerating the adjustment of industrial structure", "building a low carbon industrial system", "adjusting the industrial structure", and "building an industrial system characterized by low carbon emissions" are merged as "adjusting the industrial structure". The same process has been conducted to other preliminary dimension objectives. As a result, the final list of dimensional objectives of LCC is formulated in Table 4.

Based on the above discussion, five dimensional objectives are highlighted, including adjustment of industrial structure (D_1), optimization of energy structure (D_2), improvement of energy efficiency (D_3),

Table 4
The dimensional LCC objectives summarized by content analysis.

Code	Dimensional LCC objectives
D_1	Adjustment of industrial structure
D_2	Optimization of energy structure
D_3	Improvement of energy efficiency
D_4	Increase of carbon sinks
D_5	Improvement of management system for promoting low carbon practice

increase of carbon sinks (D_4), improvement of management system for promoting low carbon practice (D_5). The importance of these five dimensions in contributing to overall LCC objectives has been widely appreciated in previous literature. For example, optimization of energy structure is considered as an important dimensional objective affecting carbon emissions in previous research. Shen et al (2018b) pointed out that optimization of energy structure (D_2) is an important dimension contributing to overall emission reduction, as energy structure is one of the most important factors affecting carbon emissions. For another example, increasing of carbon sinks (D_4) is regarded as another important dimensional objective in LCC practice in previous research. According to the study by Lin et al (2014), increasing carbon sink is a very important dimension for reducing carbon emissions and achieving the overall LCC objectives. Therefore, this research argues the mentioned five-dimensional are the main dimensional objectives of low-carbon practicing.

4.2.2. Executable objectives

Implementation of the dimensional LCC objectives requests for the contribution by various executable objectives. It has been found that different cities have proposed their executable LCC objectives in official documents, which are listed in Appendix I. After analyzing the contents of these documents, the main executable objectives in each dimensional LCC objective can be identified, as showed in Table 5. The corresponding documents for these executable objectives are highlighted in Table 6.

4.3. Indicators for evaluating LCC executable objectives

According to the framework in Fig. 1, the third research procedure for developing MBO based LCC indicator setting method is to select the evaluation indicators for each executable LCC objective. Literature review and semi-structured interviews will be used to choose the corresponding indicators for the LCC executable objectives. Firstly, candidate indicators are selected by literature review from the LCC documents (P_1, P_2,…, P_{38}) listed in Appendix I and relevant literature. Then, the reliability and validity of the candidate indicators have been discussed though semi-structured interviews with 11 experts in a form of research forum. These experts are engaged in the discipline of low-carbon cities listed in Appendix II. As a result, indicators for evaluating each executable LCC objective are selected, as shown in Table 7.

5. Application of MBO based LCC indicator setting method

According to the MBO-based LCC indicator setting method developed in Section 3, this section will demonstrate the application of the method by referring to two case cities of Tianjin (TJ) and Chongqing (CQ) in China.

5.1. Background of the case cities

TJ and CQ have been selected as case cities because both the two cities are municipalities, and play an important role across social, economic, and environmental aspects in China. It was reported by the National Bureau of Statistics of China (2019) that CQ is a city which has the most population in China. Tianjin is an important economic center in North China and the research center for advanced manufacturing in the country. It is considered that these two cities have a very important strategic position in China. Secondly, both TJ and CQ are designed as low carbon pilot cities by the Chinese government, starting from 2012. It is feasible to conduct a case study by referring to these two municipal cities.

In fact, these two cities are quite different in geographical conditions, types of resources, energy structure, and carbon sink conditions. TJ has plenty of coal resources and its energy supply is mainly through thermal

Table 5
The main LCC executable objectives in the five dimensional objectives.

DEE	Executable objectives for LCC practice
Adjustment of industrial structure(D_1)	$E_{1\text{-}1}$ Development of strategic emerging industries
	$E_{1\text{-}2}$ Update of the conventional industries towards low-carbonization
	$E_{1\text{-}3}$ Prioritization of modern service sector for development
	$E_{1\text{-}4}$ Development of low-carbon agriculture
	$E_{1\text{-}5}$Optimization of the spatial distribution between industrial sectors
	$E_{1\text{-}6}$ Promotion of the low-carbon manufacturing industry development
	$E_{1\text{-}7}$ Promotion of waste recycling
	$E_{1\text{-}8}$ Implement the notion of low-carbon design, eg, low carbon design for building
	$E_{1\text{-}9}$ Supports to low-carbon concept of entrepreneurship
Optimization of energy structure(D_2)	$E_{2\text{-}1}$ Prioritization of non-fossil fuels for exploitation and usage
	$E_{2\text{-}2}$ Improvement of the technology for thermal power project
	$E_{2\text{-}3}$ Transformation of coal-burning boiler to gas-burning appliance
	$E_{2\text{-}4}$ Control on the energy consumption for different types of energy
	$E_{2\text{-}5}$ Opinion of coal utilization
	$E_{2\text{-}6}$ Prioritization of hydropower for development
	$E_{2\text{-}7}$ Development of Intelligent grid for application of electricity
	$E_{2\text{-}8}$ Generation of electric power for nature gas
	$E_{2\text{-}9}$ Accomplish the goal of “Gas comes into the city”
	$E_{2\text{-}10}$ Promotion of using CH_4
Improvement of energy efficiency(D_3)	$E_{3\text{-}1}$ Improvement energy efficiency in industrial sectors
	$E_{3\text{-}2}$ Promotion of green buildings
	$E_{3\text{-}3}$ Development of a low-carbon transportation system
	$E_{3\text{-}4}$ Promotion low-carbon travel
	$E_{3\text{-}5}$ Promotion low-carbon lifestyle
Increase of carbon sinks(D_4)	$E_{4\text{-}1}$ Increase of forest carbon sinks
	$E_{4\text{-}2}$ Increase urban green areas
	$E_{4\text{-}3}$ Increase of wetland carbon sinks
	$E_{4\text{-}4}$ Increase urban green building roofs
	$E_{4\text{-}5}$ Improvement in the capacity of collection and conservation of carbon dioxide
Improvement of management system for promoting low carbon practice (D_5)	$E_{5\text{-}1}$ Improvement of low-carbon policy and legislation
	$E_{5\text{-}2}$ Demonstration of low-carbon pilots projects
	$E_{5\text{-}3}$ Optimization of planning for urban spatial distribution
	$E_{5\text{-}4}$ Establishment of assessment system for appraisal of greenhouse gases
	$E_{5\text{-}5}$Introduction of a supporting mechanism for applying low-carbon technology

Note: “D” indicates that dimensional LCC objectives; “E” indicates that executable LCC objectives.

Table 6
The references for identification of LCC executable objectives.

EP	*P1*	*P2*	*P3*	*P4*	*P5*	*P6*	*P7*	*P8*	*P9*	*P10*	*P11*	*P12*	*P13*	*P14*	*P15*	*P16*	*P17*	*P18*	*P19*	*P20*	*P21*	*P22*	*P23*	*P24*	*P25*	*P26*	*P27*	*P28*	*P29*	*P30*	*P31*	*P32*	*P33*	*P34*	*P35*	*P36*	*P37*	*P38*
E_{1-1}	√	√	√	×	√	√	√	√	×	√	√	√	√	×	×	×	√	×	×	×	×	×	×	×	×	√	×	×	×	×	×	√	×	√	×	×	√	×
E_{1-2}	√	√	√	×	×	√	√	√	×	×	√	√	×	×	×	√	×	×	×	×	×	×	×	×	×	√	×	×	×	×	×	√	×	×	×	√	√	×
E_{1-3}	√	√	×	√	×	×	×	×	×	√	√	√	×	×	√	×	√	√	×	×	×	×	×	×	√	√	×	×	×	√	×	√	×	×	×	×	×	×
E_{1-4}	√	√	×	×	×	×	×	×	×	×	√	×	×	√	√	√	×	×	×	×	×	√	√	√	×	√	×	×	×	×	×	√	×	×	×	×	√	×
E_{1-5}	√	√	×	×	√	√	×	×	×	×	×	×	×	×	×	×	×	×	√	×	×	×	×	×	×	×	×	×	×	×	√	√	√	√	×	×	×	×
E_{1-6}	×	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	×	×	×	×	×	×	×	√	×	×	×	×	×	×	√	×	√	×	×	×	×
E_{1-7}	×	×	√	×	√	√	×	×	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	×	×	×	×	×	×	×	×	×	×	√	×	×	×
E_{1-8}	√	×	×	×	√	√	×	×	×	×	×	×	×	×	×	√	×	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	√	√	×	√	×
E_{1-9}	√	√	√	×	√	√	×	×	×	×	√	×	×	×	×	×	×	√	×	×	×	×	×	√	√	×	×	×	×	×	×	×	×	√	×	×	×	×
E_{2-1}	√	×	×	√	×	×	×	×	√	√	×	√	×	×	×	×	√	×	×	×	√	×	√	×	×	×	×	×	×	×	×	×	×	×	×	×	√	×
E_{2-2}	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	×	×	×	×
E_{2-3}	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	×	×	×	×	×	×	×	×	×	√	×	×
E_{2-4}	×	√	×	×	×	×	×	×	×	×	√	×	×	×	×	√	√	√	√	√	×	×	×	×	×	×	×	√	×	×	×	×	×	×	×	×	×	√
E_{2-5}	×	√	×	×	×	×	×	×	×	×	×	√	×	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	×	×	×	×	√	×	×	×
E_{2-6}	×	√	√	×	×	×	×	×	×	×	×	×	×	×	×	√	√	√	√	×	×	×	×	×	×	×	×	×	×	×	×	√	×	×	×	√	×	√
E_{2-7}	√	√	×	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	×	×	×	×	×	×	×	√	×	×	√	×	×	√
E_{2-8}	√	×	×	×	×	×	×	×	×	×	√	×	×	×	×	√	×	√	×	×	×	×	×	×	×	×	√	×	×	×	×	×	×	×	×	×	×	×
E_{2-9}	√	√	√	×	√	√	×	×	×	×	√	×	×	×	×	×	×	√	√	×	×	×	×	×	√	×	×	×	×	√	×	×	×	×	×	×	×	√
E_{3-1}	√	√	√	√	√	√	×	√	×	√	√	×	×	×	√	×	×	×	×	√	×	×	√	×	×	×	×	×	×	×	×	×	×	×	√	×	×	×
E_{3-2}	×	×	×	√	×	×	√	√	√	√	×	√	×	√	√	×	√	×	×	√	√	×	√	√	×	√	√	×	×	×	×	×	×	×	√	×	×	×
E_{3-3}	√	×	×	√	×	×	√	√	√	√	×	√	√	√	√	×	×	√	√	×	√	×	√	√	√	√	×	×	×	×	×	×	×	×	√	×	×	×
E_{3-4}	√	×	×	√	√	√	√	√	×	×	√	×	√	×	×	×	×	√	√	√	√	×	×	√	×	×	×	×	×	×	×	√	×	×	×	√	×	√
E_{3-5}	×	×	√	×	×	×	×	√	×	×	×	√	×	×	×	×	×	×	×	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
E_{4-1}	×	×	×	×	√	√	×	√	×	√	√	×	√	×	×	×	×	×	√	√	×	×	√	√	×	√	√	×	×	×	×	×	√	×	√	√	×	×
E_{4-2}	×	×	×	√	×	×	×	×	×	√	√	×	×	×	√	×	×	×	√	√	×	√	×	×	×	×	×	×	×	×	√	×	×	×	×	×	×	×
E_{4-3}	√	×	×	×	×	×	×	×	×	×	√	√	×	×	√	×	√	×	×	√	×	×	×	×	×	×	×	×	×	√	×	×	×	×	×	√	×	×
E_{4-4}	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	√	×	×	√	×	×	×	×	×	√	√	×	×	×	√
E_{4-5}	×	√	√	×	√	√	×	×	×	√	√	×	×	×	×	√	×	×	×	×	×	×	×	√	×	×	×	×	×	×	×	×	×	×	×	×	×	×
E_{5-1}	√	√	√	√	√	√	×	√	×	×	√	×	×	×	×	×	×	×	×	√	×	×	×	√	×	√	×	√	×	√	×	×	×	×	×	×	×	×
E_{5-2}	√	√	√	√	√	√	×	√	×	√	√	×	×	×	√	×	×	√	×	×	√	√	√	√	×	√	×	×	√	×	√	√	×	×	×	×	√	√
E_{5-3}	×	√	√	√	√	√	×	√	×	×	√	×	×	×	×	√	×	√	√	√	√	×	×	×	×	×	√	×	√	√	√	×	×	√	×	√	√	×
E_{5-4}	√	√	√	√	√	×	×	×	×	√	×	×	×	√	×	×	×	√	×	×	×	×	√	√	×	×	×	×	×	×	√	×	×	√	×	√	×	×
E_{5-5}	√	√	×	√	√	×	×	×	×	√	×	×	×	√	×	×	×	√	×	×	√	×	√	√	×	×	×	×	×	×	×	×	×	×	×	√	×	√

Note: "√" indicates that the executable LCC objectives have been included in the corresponding reference, "×" indicates that the executable LCC objectives have not been included in the corresponding reference, the name of the policy document P* is listed in Appendix I.

Table 7
The indicators for evaluating each executable objective.

E	Indicators
E_{1-1}	I_{1-1-1} The proportion of strategic emerging industries added value to GDP (P_3; P_{11})
E_{1-2}	I_{1-2-1} The proportion of high and new technology industry added value to GDP (P_3; P_{10}; Li et al., 2019)
E_{1-3}	I_{1-3-1} The added value of the modern service industry accounts for the proportion of the third industry (P_3; P_{11})
E_{1-4}	I_{1-4-1} Livestock farming amount per capita (Lin et al., 2014)
	I_{1-4-2} Agricultural cultivation area per capita (Lin et al., 2014)
	I_{1-4-3} Fertilizer used per agricultural land (Lin et al., 2014)
E_{1-5}	I_{1-5-1} The distance between work and home (P_6)
E_{1-6}	I_{1-6-1} Carbon dioxide emissions from manufacturing (Hang et al., 2019)
E_{1-7}	I_{1-7-1} Harmless disposal rate in household garbage (P_6)
	I_{1-7-2} The supply rate of vein industry resources (P_6)
	I_{1-7-3} The proportion of venous industry output value in GDP (P_6)
E_{1-8}	I_{1-8-1} Number of low-carbon design competitions (P_6)
E_{1-9}	I_{1-9-1} The amount of investment for low-carbon industry (P_6)
E_{2-1}	I_{2-1-1} The proportion of non-fossil energy to primary energy (Zhou et al., 2019; P10)
	I_{2-1-2} The proportion of zero-carbon energy in primary energy (Yang et al., 2018)
E_{2-2}	I_{2-2-1} The proportion of thermal power capacity accounts for the total installed capacity (Yang et al., 2018)
E_{2-3}	I_{2-3-1} The number of coal-to-gas projects (Zhou et al., 2019)
E_{2-4}	I_{2-4-1} The consumption proportion of coal in primary energy (Zou and Luo, 2019)
E_{2-5}	I_{2-5-1} The efficiency of coal utilization (Wang et al., 2019b)
E_{2-6}	I_{2-6-1} Number of hydropower projects (P_1)
E_{2-7}	I_{2-7-1} The ratio of intelligent substation (Hang et al., 2019; Xin, 2011)
E_{2-8}	I_{2-8-1} The proportion of cogeneration (He et al., 2019)
E_{2-9}	I_{2-9-1} The proportion of clean energy (Hong and Wen, 2018)
E_{3-1}	I_{3-1-1} Comprehensive utilization rate of industrial solid waste (Guan, 2014; Wang et al., 2019b,c; Yang et al., 2018)
	I_{3-1-2} Compliance rate of industrial wastewater (Tan et al., 2017; Xin, 2011)
E_{3-2}	I_{3-2-1}The proportion of energy-saving building (Song et al., 2018)
	I_{3-2-2} Energy consumption density in a building (Ahn and Sohn, 2019)
	I_{3-2-3} The proportion of energy-saving renovation of public buildings (Xin, 2011; Huang et al., 2014)
	I_{3-2-4} The proportion of developing energy-saving building (Xin, 2011)
E_{3-3}	I_{3-3-1} The number of buses per 10,000 people (Wang and Cao, 2017; Xin, 2011)
	I_{3-3-2} Average walking distance to BRT station (Wang and Cao, 2017; Xin, 2011)
	I_{3-3-4} The proportion of public transportation (Chang et al., 2019)
	I_{3-3-5} Area of urban road per capita (Lee and Erickson, 2017)
E_{3-4}	I_{3-4-1} The ratio of clean transportation (Mathur, 2019)
	I_{3-4-2} Length of public transport network (P_3)
	I_{3-4-3} The rate of green traveling (Xin, 2011; Zhou et al., 2015b)
	I_{3-4-4}The popularity of energy-saving household appliances (Jia et al., 2018)
E_{3-5}	I_{3-5-1} The proportion of low-carbon consumption expenditure (Apergis et al., 2018; Guan, 2014; Xin, 2011)
E_{4-1}	I_{4-1-1} The forest coverage rate (P_1; P_{11})
	I_{4-1-2} The stock of living wood growing (P_{21})
	I_{4-1-3} The proportion of forest area (P_{21})
E_{4-2}	I_{4-2-1} The proportion of nature reserve (Huang et al., 2019)
E_{4-3}	I_{4-3-1} Green coverage of built-up areas (Sun et al., 2019; Xin, 2011)
	I_{4-3-2} Green channel mileage per unit area (P_1)
	I_{4-3-3} Per capita park green space (Wang et al., 2019a)
	I_{4-3-4} Per capita green area (Badiu et al., 2016; Xin, 2011)
E_{4-4}	I_{4-4-1} Area of urban green building roofs (P_1)
E_{4-5}	I_{4-5-1} Number of carbon dioxide capture, utilization and storage projects (Guan, 2014)
E_{5-1}	I_{5-1-1} Score of Low carbon policy improvement (Xin, 2011)
E_{5-2}	I_{5-2-1} Score of low-carbon demonstration projects (Du, 2018)
E_{5-3}	I_{5-3-1} Score of city planning rationality (Du, 2018)
E_{5-4}	I_{5-4-1} Score of greenhouse gas statistical accounting and evaluation (Zhu et al., 2018)
E_{5-5}	I_{5-5-1} Score of Low-carbon technology innovation (Du, 2018)

Note: "E" indicates that the executable LCC objectives; "I" indicates indicator.

power generation. Whilst, CQ has plenty of water resources with the main energy supply of hydroelectric power. In terms of carbon sink conditions, TJ has the forest coverage rate of 9.87% in 2018 (National Bureau of Statistics of China, 2019), whilst that in CQ was 48.3%. These facts demonstrate that the two case cities have very different backgrounds. It is therefore important for the two cities to select tailor-made indicators to guide their LCC practice, thus their overall objectives can be achieved. And this can be done by adopting the MBO method introduced in Section 3. The application of the method is through the three procedures designed in Fig. 1.

5.2. LCC objectives for TJ and CQ

According to MBO based method, LCC Objectives are classified in a hierarchy to overall dimensional and executable objectives.

5.2.1. Overall LCC objectives for TJ and CQ

According to Table 3, the overall objectives TP_{tc} of the two cities is 2025 and 2030 respectively. It is considered that these two cities need to have customized LCC indicators to guide their LCC practice to achieve their overall LCC objectives. Therefore, tailor-made indicators for these two cases will be set.

5.2.2. Dimensional LCC objectives for TJ and CQ

The dimensional LCC objectives formulated in Table 4 are applications for both TJ and CQ. However, the relative importance between these dimensional objectives is different in the two case cities. By examining the LCC policy documents published by TJ and CQ governments, TJ considered more about the dimensional LCC objective of increasing carbon sink (D_4). Chongqing paid more attention to the dimensional LCC objective of adjustment industrial structure (D_1). The difference in attention between the two cities is due to the different backgrounds of the two cities. According to the National Bureau of Statistics of China (2019), the proportion of tertiary industry and forest coverage rate in TJ and CQ during the period from 2006 to 2018 is listed in Table 8. By using the data in Table 8, the distribution of the proportion of tertiary industry (I_1) and forest coverage rate (I_2) in the two case cities can be presented in Fig. 2 and Fig. 3. It can be seen from Fig. 2 that the value of the proportion of the tertiary industry in GDP in TJ is higher than that of CQ. It indicates that Tianjin has fewer carbon emissions pressure than Chongqing in the dimension of the industrial structure. On the other hand, Fig. 3 tells that the forest coverage rate in CQ is much higher than that in TJ, indicating that CQ has more carbon sink.

5.2.3. Executable LCC objectives for TJ and CQ

As the two case cities have different priorities in defining their dimensional objectives, the executable LCC objectives suitable for the two case cities are accordingly different. By referring to Table 6, TJ has defined its executable LCC objective in its LCC policy (P_1), CQ has defined its executable LCC objective in its LCC policy (P_2), the executable objectives of TJ and CQ can be shown in Table 9.

Table 8
The proportion of tertiary industry and forest coverage rate in TJ and CQ.

Indicator	City	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
I_1	TJ	32.00	32.00	34.00	35.00	37.00	39.00	41.00	42.10	43.10	38.40	38.43	38.43	43.11
	CQ	8.10	8.10	8.10	9.90	9.90	9.90	9.90	9.90	9.90	9.90	9.87	9.87	12.07
I_2	TJ	44.82	42.40	40.97	37.89	36.35	36.20	39.39	41.53	46.78	47.70	48.1	49	52.3
	CQ	50.59	52.58	53.66	59.36	57.28	58.05	60.45	62.24	64.82	67.76	56.4	58	58.6

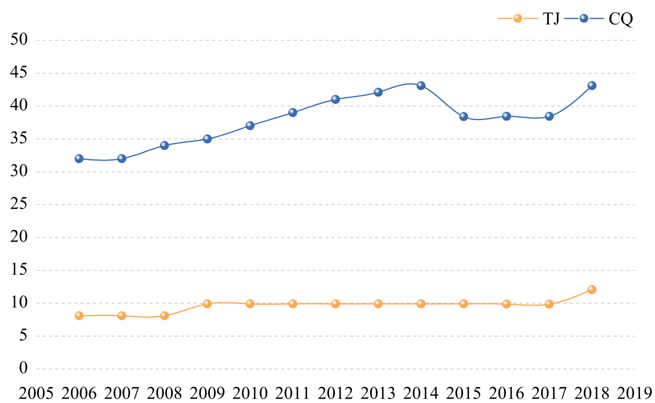

Fig. 2. Proportion of the tertiary industry in GDP in TJ and CQ from 2006 to 2018.

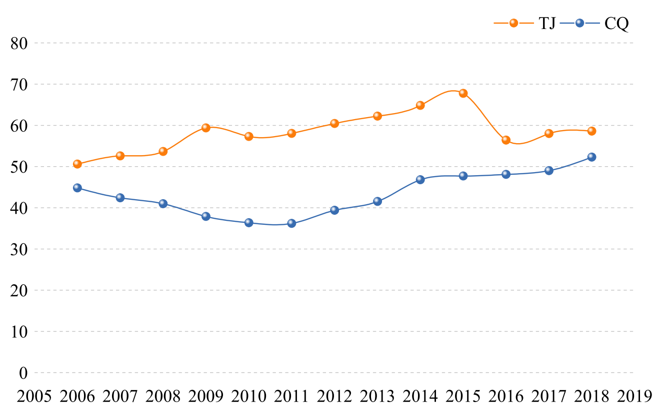

Fig. 3. Forest coverage rate in TJ and CQ from 2006 to 2018.

Table 9
The executable objectives in TJ and CQ for each dimensional objectives.

ED	Executable objectives
D_1	TJ:E_{1-1}, E_{1-2}, E_{1-3}, E_{1-4}, E_{1-5} CQ:E_{1-1}, E_{1-2}, $E4_{1-3}$, E_{1-4}, E_{1-5}, E_{1-6}
D_2	TJ:E_{2-1}, E_{2-2}, E_{2-3}, E_{2-4}, E_{2-5}, E_{2-9} CQ:E_{2-1}, E_{2-4}, E_{2-5}, E_{2-6}, E_{2-7}, E_{2-8}, E_{2-9}
D_3	TJ:E_{3-1}, E_{3-2}, E_{3-3}, E_{3-4}, E_{3-5} CQ:E_{3-1}, E_{3-2}, E_{3-3}, E_{3-4}, E_{3-5}
D_4	TJ:E_{4-1}, E_{4-2} CQ:E_{4-4}, E_{4-5}
D_5	TJ:E_{5-1}, E_{5-2}, E_{5-4}, E_{5-5} CQ:E_{5-1}, E_{5-2}, E_{5-3}, E_{5-4}, E_{5-5}

Note: “D” indicates dimensional LCC objectives.

5.3. *Indicators for evaluating LCC executable objectives for TJ and CQ*

Table 7 has presented a general list of indicators for all types of executable objectives. By referring to the indicators listed in Table 7, the indicators corresponding to each executable LCC objective in Table 8 can be established, as shown in Table 10.

The indicator-setting in Table 10 can be considered tailor-made for TJ and CQ. Whilst two case cities share some indicators, and each city has different tailor-made indicators. For a simple calculation based on Table 10, the ratio between the different indicators to adopted by two case cites and the total number of indicators corresponding to each dimensional LCC objective can be found as 12.25% for D_1 (Adjustment of industrial structure), 50.00% for D_2 (Optimization of energy structure), 0.00% for D_3 (Improvement of energy efficiency), 100.00% for D_4 (Increase of carbon sinks) and 20.00% for D_5 (Improvement of management system for promoting low carbon practice). These data show that TJ and CQ shall adopt different sets of indicators for guiding their LCC practice. For example, in referring to the dimensional objective for dimension D_4 (Increase of carbon sinks), the two case cities should adopt different indicators. This analysis further supports that the MBO based indicator setting method can select indicators for guiding their LCC practice.

Taking the indicators set for the LCC dimensional objective D_4 (Increase of carbon sinks) for further discussion, TJ is advised to use the indicators I_{4-1-1} (The forest coverage rate), I_{4-1-2} (The stock of living wood growing), I_{4-1-3} (The proportion of forest area), I_{4-1-4} (The stock of forest growing) and I_{4-2-1} (Green area per capita), whilst CQ should employ the indicator of I_{4-4-1} (Area of urban green building roofs), I_{4-5-1} (Number of carbon dioxide capture, utilization and storage projects). The indicators of I_{4-1-1}, I_{4-1-2}, I_{4-1-3} and I_{4-1-4} can help TJ to evaluate the performance of the executable LCC objective E_{4-1} (increasing of forest carbon sinks) as presented in Table 7 and the indicator I_{4-2-1} can help TJ evaluate the performance of the executable LCC objective E_{4-2} (Increasing urban green areas). TJ has a very low forest coverage rate with few green areas. According to the report published by the National Bureau of Statistics of China (2019), the forest coverage rate of TJ in 2018 was 9.87%, ranking 29th among 31 provinces in China. Therefore, it is considered that increasing forest carbon sinks and urban green areas should be the main executable objectives for TJ to improve its carbon sink. Therefore, the application of the indicators I_{4-1-1}, I_{4-1-2}, I_{4-1-3}, I_{4-1-4} and I_{4-2-1} can guide TJ to complete the two executable objectives E_{4-1} (Increase of forest carbon sinks) and E_{4-2} (Increase urban green areas). On the other hand, according to Table 10, CQ should employ I_{4-4-1} can evaluate the performance of E_{4-4} (Increasing green building roofs), and the indicator I_{4-5-1} can evaluate the performance of the E_{4-5} (Improving the capacity of collection and conservation of carbon dioxide). As a mountainous city, CQ has a geographical advantage to implement E_{4-4}. Furthermore, since CQ is designed as a demonstration city of developing

Table 10
The indicators for the executable objectives in TJ and CQ.

DII	Indicators for both TJ and CQ	Indicators only for TJ	Indicators only for CQ
D_1	I_{1-1-1}, I_{1-2-1}, I_{1-3-1}, I_{1-4-1}, I_{1-4-2}, I_{1-4-3}, I_{1-5-1}	–	I_{1-6-1}
D_2	I_{2-1-1}, I_{2-1-2}, I_{2-4-1}, I_{2-5-1}, I_{2-9-1}	I_{2-2-1}, I_{2-3-1}	I_{2-6-1}, I_{2-7-1}, I_{2-8-1}
D_3	I_{3-1-1}, I_{3-1-2}, I_{3-2-1}, I_{3-2-2}, I_{3-2-3}, I_{3-2-4}, I_{3-3-1}, I_{3-3-2}, I_{3-3-3}, I_{3-3-4}, I_{3-5-1}	–	–
D_4	–	I_{4-1-1}, I_{4-1-2}, I_{4-1-3}, I_{4-1-4}, I_{4-2-1}	I_{4-4-1}, I_{4-5-1}
D_5	I_{5-1-1}, I_{5-2-1}, I_{5-4-1}, I_{5-5-1}	–	I_{5-3-1}

Note: “D” indicates dimensional LCC objectives; “I” indicates indicator.

carbon capture technology, it is feasible for CQ to implement executable objective $E_{4\text{-}5}$ for CQ. So, it is considered that these two indicators $I_{4\text{-}4\text{-}1}$ and $I_{4\text{-}5\text{-}1}$ can guide the implementation of $E_{4\text{-}4}$ and $E_{4\text{-}5}$.

For another example, in referring to the dimensional LCC objective D_2 (Optimization of energy structure), Table 10 suggests that TJ and CQ should employ a different set of indicators to guide the implementation of their executable objectives. TJ should employ the specific indicators $I_{2\text{-}2\text{-}1}$ (The proportion of thermal power capacity accounts for the total installed capacity) and $I_{2\text{-}3\text{-}1}$ (The number of coal-to-gas projects), in which $I_{2\text{-}2\text{-}1}$ can help evaluate the performance of the executable objective $E_{2\text{-}2}$ (improving technology for thermal power project), and $I_{2\text{-}3\text{-}1}$ can evaluate the performance of the executable objective $E_{2\text{-}3}$ (Transformation of coal-burning boiler appliance to gas-burning appliance). TJ has the main energy source of coal, and it should design its executable LCC objectives with the incorporation of the way of using coal. In line with this, the executable LCC objectives $E_{2\text{-}2}$ and $E_{2\text{-}3}$ are properly defined to optimize the energy structure in TJ. Therefore, the adoption of tailor-made indicators $I_{2\text{-}2\text{-}1}$ (The proportion of thermal power capacity accounts in the total installed capacity) and $I_{2\text{-}3\text{-}1}$ (The number of coal-to-gas projects) can guide the implementation of the executable objectives $E_{2\text{-}2}$ (improving technology for thermal power project) and $E_{2\text{-}3}$ (Transformation of coal-burning boiler appliance to gas-burning appliance). On the other hand, Chongqing has rich water and gas resources, thus the city should define its executable objective with the incorporation of the way of using water and gas. In line with this, the executive objectives $E_{2\text{-}6}$ (Prioritization of hydropower for development), $E_{2\text{-}7}$ (Development of Intelligent grid for application of electrical), and $E_{2\text{-}8}$ (generation of electric power for natural gas) are defined as important executable objectives. Accordingly, the indicators $I_{2\text{-}6\text{-}1}$ (Number of hydropower projects), $I_{2\text{-}7\text{-}1}$ (The ratio of intelligent substation), $I_{2\text{-}8\text{-}1}$ (The proportion of cogeneration) are selected to evaluate the performance of $E_{2\text{-}6}$, $E_{2\text{-}7}$ (Development of Intelligent grid for application of electrical), and $E_{2\text{-}8}$ (generation of electric power for natural gas) respectively.

The above demonstrates that the MBO-based approach introduced in Section 3 can assist in setting tailor-made indicators for TJ and CQ to guide their LCC practice.

6. Discussion

In the process of low carbon practice, different cities have set different LCC objectives at specific overall, dimensional and executable levels due to their different local conditions. Therefore, a method is needed to assist different cities in setting their tailor-made indicators for guiding their LCC practice towards achieving their scientific LCC objectives. There is no existing study presenting indicator setting method with considering specific executable LCC objectives. This study considers that the MBO principle provides a theoretical base of how to set LCC indicator which echoes the LCC objective. In line with this theoretical approach, MBO based indicator setting method is proposed in this study. There are three basic procedures in this LCC indicator setting method, including the identification of the overall LCC objectives, decomposition of the overall LCC objectives into the dimensional and executable LCC objectives, selection indicators for evaluating LCC executable objectives.

The proposed MBO method is proved effective through the case demonstration in the previous study. In the demonstration, the application of the method suggests that TJ and CQ should adopt different indicator $I_{1\text{-}6\text{-}1}$in the dimensional objective D_1, $I_{2\text{-}2\text{-}1}$, $I_{2\text{-}3\text{-}1}$, $I_{2\text{-}6\text{-}1}$, $I_{2\text{-}7\text{-}1}$, $I_{2\text{-}8\text{-}1}$in the dimensional objective D_2, $I_{4\text{-}1\text{-}1}$, $I_{4\text{-}1\text{-}2}$, $I_{4\text{-}1\text{-}3}$, $I_{4\text{-}1\text{-}4}$, $I_{4\text{-}2\text{-}1}$, $I_{4\text{-}4\text{-}1}$, $I_{4\text{-}5\text{-}1}$ in the dimensional objective D_4 and $I_{5\text{-}3\text{-}1}$ in the dimensional objective D_5. These tailor-made indicators can guide their specific executable objectives. The reliability and validity of the MBO based indicator setting method have also been discussed by organizing a research forum. The forum has engaged researchers in the discipline of low carbon city. The forum discussion supports the reliability and validity of the method.

The successful application of the MBO based indicator setting method will depend on the proper understanding of the overall LCC objectives, the proper identification of dimensional and executable LCC objectives. When setting the overall LCC objective, the local conditions of the city must be considered, for example, economic conditions, industrial structure, and carbon sink. As demonstrated in the case study, TJ has set its overall LCC as TP_{tc} 2025 and CQ as TP_{tc} 2030. Different cities should set different overall LCC objectives in their LCC development plan by considering their different local backgrounds. This point has also been emphasized by previous research, for example, Shuai et al. (2017), pointing out that local conditions such as energy structure and industrial structure are the main factors affecting carbon emissions and these factors should be fully taken into account when setting local emission reduction objectives. Furthermore, the overall LCC objective is decomposed to five dimensional LCC objectives, and different cities should give different priorities to these five aspects due to their specific backgrounds. In the demonstration, TJ emphasized more about the dimensional LCC objective of increasing carbon sink (D_4), and Chongqing paid more attention to the dimensional LCC objective of adjustment industrial structure (D_1). In general, the Northern cities in China pay more attention to the dimensional objective for optimizing energy structure (D_3) because Northern cities have more energy consumption for heating in Winter. Northern cities also pay more attention to the dimensional objective of increasing the carbon sink (D_4), because the forest coverage rate is low in these cities due to their climatic conditions. On the other hand, some economically backward cities, such as Urumqi and Zunyi, pay more attention to the adjustment of industrial structure (D_1), to reduce carbon emission caused by convention industries. However, the effectiveness of the dimensional LCC objective will depend on the implementation of the executive LCC objective, and the executive objective should be defined properly in a way that can be measured. As shown in the demonstration, TJ has the main energy source of coal, and it has designed its executable LCC objective $E_{2\text{-}2}$ (Improvement of the technology for thermal power project), which can be measured efficiently by the indicators $I_{2\text{-}2}$ (The proportion of thermal power capacity accounts in the total installed capacity). Chongqing, on the other hand, has defined its executive objective $E_{2\text{-}6}$ (Prioritization of hydropower for development) which can be measured efficiently by the indicators $I_{2\text{-}6\text{-}1}$ (Number of hydropower projects), since it has rich water resources. In a word, the implementation of executable objectives must be guided by measurable indicators.

7. Conclusion

The conclusions from the results in this study can be drawn as follows. Firstly, tailor-made evaluation indicators are needed for assisting different cities to guide their LCC practice to ensure that different backgrounds are considered. The indicators set in this study can help different cities achieve their defined LCC objectives. Secondly, the MBO principle can help develop the tailor-made indicator setting method that can echo specific objectives defined in different cities. Thirdly, the demonstration of the two case cities has further shown the effectiveness of using the MBO indicator setting method to enable the achievement of LCC objectives.

The significance of this study can be highlighted as follows. The study contributes to the development of literature in the discipline of low carbon practice. It offers an innovative method for setting tailor-made indicators to guide LCC practice in different cities where differences exist inherently. This research extends the application of the principle to promote the LCC practice. From a practical perspective, the result of this study provides an effective method for local governments to set effective indicators to guide their LCC practice. The application of the tailor-made indicators can ensure that performance of specific LCC executable objectives can be evaluated effectively. This will help achieve the objectives defined in specific cities. In other words, the deployment of the tailor-made indicators through applying the MBO based indicator setting method can help cities choose a set of effective and applicable indicators to avoid indicators application indiscriminately.

Limitations of this study can be appreciated in only two case cities. TJ and CQ are used for empirical analysis to demonstrate the application of the MBO method introduced in this study. It is recommended that the application of this method should be investigated by engaging in more cities. It is father comment to study the application of MBO principal to the formula for selecting evaluate indicate for getting the practice of other types of city development patterns such as smart city or sponge city.

CRediT authorship contribution statement

Xiaoyun Du: Conceptualization, Methodology, Investigation, Writing - original draft. **Liyin Shen:** Supervision, Project administration. **Siu Wai Wong:** Supervision. **Conghui Meng:**. :. **Guangyu Cheng:** Visualization, Validation. **Fuyi Yao:**.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This research work was supported by the Fundamental Research Funds for the Central University (No. “2018CDJSK03PY07”, No. “2019CDJSK03PT06”), National Planning Office of Philosophy and Social Science Foundation of China under Grant (No. “17ZDA062”).

Appendix

Appendix I Low carbon policy document enacted by pilot cities in China

No.	Name of the policy document	City
P_1	Implementation plan of Tianjin’s low-carbon city pilot work	Tianjin
P_2	Chongqing’s 12th five-year plan to control greenhouse gas emissions and pilot low-carbon projects	Chongqing
P_3	Medium and long term planning of low carbon development in Shenzhen (2011 to 2020)	Shenzhen
P_4	Implementation program of pilot work of low-carbon city in Xiamen	Xiamen
P_5	Outline of overall planning for low carbon cities in Xiamen	Xiamen
P_6	The 12th five-year plan for low-carbon development in Hangzhou	Hangzhou
P_7	Implementation program of national low-carbon pilot work in Nanchang city	Nanchang
P_8	Implementation program of the low-carbon pilot work in Guiyang City	Guiyang
P_9	Opinions of Baoding Municipal People’s Government on the construction of the low-carbon city	Baoding
P_{10}	Jincheng’s low carbon development plan (2013–2020)	Jincheng
P_{11}	Implementation program of the low-carbon pilot work in Jincheng City	Jincheng
P_{12}	Key points of the 12th five-year plan of low-carbon city pilot project in Shijiazhuang	Shijiazhuang
P_{13}	Eight executable objectives to build a low-carbon city in Shijiazhuang	Shijiazhuang
P_{14}	Opinions on the implementation of the low-carbon pilot city construction in Qinhuangdao city	Qinhuangdao
P_{15}	The low carbon development plan of Suzhou city	Suzhou
P_{16}	Huaian’s 12th five-year plan to control greenhouse gas emissions and pilot low-carbon projects	Huai’an
P_{17}	The work plan of Zhenjiang’s low-carbon city construction in 2015	Zhenjiang
P_{18}	Implementation program of the low-carbon pilot work in Ningbo City	Ningbo
P_{19}	Implementation program of the low-carbon pilot work in Wenzhou City	Wenzhou
P_{20}	Implementation program of the low-carbon pilot work in Nanping City	Nanping
P_{21}	Implementation program of the low-carbon pilot work in Jingdezhen City	Jingdezhen
P_{22}	Implementation program of the low-carbon pilot work in Ganzhou City	Ganzhou
P_{23}	Key points and division of tasks in the pilot work of low-carbon city in Ganzhou city	Ganzhou
P_{24}	Opinions of Ganzhou Municipal People’s Government on the construction of the low-carbon city	Ganzhou
P_{25}	The low carbon development plan of Qingdao city (2014–2020)	Qingdao
P_{26}	Guidance of Jiyuan Municipal People’s Government on the construction of the low-carbon city	Jiyuan
P_{27}	Low-carbon city pilot work objectives and tasks notice in Jiyuan	Jiyuan
P_{28}	Action plan for peak carbon emission in Wuhan (2017–2022)	Wuhan
P_{29}	Implementation Suggestions on promoting low-carbon development and building ecological cities	Guangzhou
P_{30}	The 13th five-year plan for the development of low-carbon cities in Guilin	Guilin
P_{31}	Implementation program of national low-carbon pilot work in Guangyuan city	Guangyuan
P_{32}	Guangyuan’s 13th five-year plan for low-carbon development	Guangyuan
P_{33}	Preliminary implementation program of the low-carbon pilot work in Zunyi city	Zunyi
P_{34}	Implementation program of low-carbon construction in Kunming	Kunming
P_{35}	Kunming people’s government on the construction of low-carbon Kunming opinions	Kunming
P_{36}	Implementation program of the low-carbon pilot work inYan’an City	Yan’an
P_{37}	Implementation program of the low-carbon pilot work in Jinchang City	Jinchang
P_{38}	Implementation program of the low-carbon pilot work in Urumqi City	Urumqi

Appendix. IIThe information of questionnaire survey expert

Expert	Affiliation
E_1	Chongqing Development and Reform Commission
E_2	Chongqing Development and Reform Commission
E_3	Guangdong Building Research Institute Group
E_4	Guangdong Building Research Institute Group
E_5	Guangdong University of Technology

(continued on next page)

(*continued*)

Expert	Affiliation
E_6	Shanghai Modern Service Industry Association
E_7	Zhejiang university,
E_8	Chinese Academy of Science and Technology for Development
E_9	Chinese Academy of Science and Technology for Development
E_{10}	Shenzhen Municipal Development and Reform Commission
E_{11}	Planning, Land and Resources Commission of Shenzhen Municipality

References

Ahn, Y., Sohn, D.W., 2019. The effect of neighborhood-level urban form on residential building energy use: a GIS-based model using building energy benchmarking data in Seattle. Energy Build. 196, 124–133.

Apergis, N., Jebli, M.B., Youssef, S.B., 2018. Do renewable energy consumption and health expenditures decrease carbon dioxide emissions? Evidence for sub-Saharan Africa countries. Renewable Energy 127, 1011–1016.

Badiu, D.L., Iojă, C.I., Pătroescu, M., Breuste, J., Artmann, M., Niță, M.R., Onose, D.A., 2016. Is urban green space per capita a valuable target to achieve cities' sustainability goals? Romania as a case study. Ecol. Ind. 70, 53–66.

Chang, X., Ma, T., Wu, R., 2019. Impact of urban development on residents' public transportation travel energy consumption in China: An analysis of hydrogen fuel cell vehicle alternatives. Int. J. Hydrogen Energy 44 (30), 16015–16027.

Du, X.Y. (2018). Research on the evaluation of low-carbon city practice (Doctoral dissertation). Available from Cnki database. (In Chinese).

Erdogan, B., Kraimer, M.L., Liden, R.C., 2001. Procedural justice as a two-dimensional construct: an examination in the performance appraisal context. J. Appl. Behav. Sci. 37 (2), 205–222.

Fu, Y., Liu, Y.J., Wang, Y.L., 2010. Research on evaluation method and support system of low-carbon cities. China Populat. Resourc. Environ. 20 (8), 44–47 (In Chinese).

Guan, C., 2014. Research on Residents' Low-carbon Consumption in Heilongjiang Province. IERI Procedia 8, 35–40.

Hang, Y., Wang, Q., Zhou, D., Zhang, L., 2019. Factors influencing the progress in decoupling economic growth from carbon dioxide emissions in China's manufacturing industry. Resour. Conserv. Recycl. 146, 77–88.

He, W.F., Wu, F., Kong, Y.P., Wen, T., Chen, J.J., Han, D., 2019. Parametric analysis of a power-water cogeneration system based on single-extraction organic Rankine cycle. Appl. Therm. Eng. 148, 382–390.

Hong, T.L., Wen, J.L., 2018. The analysis of effects of clean energy power generation. Energy Procedia 152, 947–952.

Huang, J. L., H., Gao, T., Feng, W., Chen, Y., Zhou, T. (2014). Thermal properties optimization of envelope in energy-saving renovation of existing public buildings. Energy and Buildings, 75, 504-510.

Huang, L., Shao, Q., Liu, J., 2019. Assessing the conservation effects of nature reserve networks under climate variability over the northeastern Tibetan plateau. Ecol. Ind. 96, 163–173.

IPCC. (2014). Climate Change 2013: the Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Jia, J.J., Xu, J.H., Fan, Y., 2018. Public acceptance of household energy-saving executable objectives in Beijing: Heterogeneous preferences and policy implications. Energy Policy 113, 487–499.

Keeney, R.L., 1994. Creativity in decision making with value-focused thinking. MIT Sloan Manage. Rev. 35 (4), 33.

Lee, C.M., Erickson, P., 2017. How does local economic development in cities affect global GHG emissions? Sustain. Cities Society 35, 626–636.

Li, L., Hong, X., Peng, K., 2019. A spatial panel analysis of carbon emissions, economic growth and high-technology industry in China. Struct. Change Econom. Dyn. 49, 83–92.

Lin, J., Jacoby, J., Cui, S., Liu, Y., Lin, T., 2014. A model for developing a target integrated low carbon city indicator system: the case of Xiamen, China. Ecol. Ind. 40, 51–57.

Mathur, S., 2019. An evaluative framework for examining the use of land value capture to fund public transportation projects. Land Use Policy 86, 357–364.

Mi, Z.F., Pan, S.Y., Yu, H., Wei, Y.M., 2015. Potential impacts of industrial structure on energy consumption and CO2 emission: a case study of Beijing. J. Cleaner Prod. 103, 455–462.

National Bureau of Statistics of China, (2019). China Statistical Yearbook, Beijing.

National Development and Reform Commission (NDRC). (2016).13th FYP of Energy Development. http://www.ndrc.gov.cn/zcfb/zcfbtz/201701/t20170117_835278.html.

Nayab, N., 2009. Management by objectives. Publications Oboulo. com.

Pamlin Dennis. Low carbon city index 2009.http://www.pamlin.net.

Price, L., Zhou, N., Fridley, D., Ohshita, S., Lu, H., Zheng, N., Fino-Chen, C., 2013. Development of a low-carbon indicator system for China. Habitat Int. 37, 4–21.

Reed, M.S., Fraser, E.D., Dougill, A.J., 2006. An adaptive learning process for developing and applying sustainability indicators with local communities. Ecol. Econ. 59 (4), 406–418.

Rodgers, R., Hunter, J.E., 1992. A foundation of good management practice in government: management by objectives. Public Administration Review 52 (1), 27.

Sharma, T., Balachandra, P., 2015. Benchmarking sustainability of Indian electricity system: an indicator approach. Appl. Energy 142, 206–220.

Shen, L., Huang, Z., Wong, S.W., Liao, S., Lou, Y., 2018a. A holistic evaluation of smart city performance in the context of China. J. Cleaner Prod. 200, 667–679.

Shen, L., Wu, Y., Shuai, C., Lu, W., Chau, K.W., Chen, X., 2018b. Analysis on the evolution of low carbon city from process characteristic perspective. J. Cleaner Prod. 187, 348–360.

Shi, Q., Chen, J., Shen, L., 2017. Driving factors of the changes in the carbon emissions in the Chinese construction industry. J. Cleaner Prod. 166, 615–627.

Shuai, C., Chen, X., Shen, L., Jiao, L., Wu, Y., Tan, Y., 2017. The turning points of carbon Kuznets curve: evidences from panel and time-series data of 164 countries. J. Cleaner Prod. 162, 1031–1047.

Singh, R.K., Murty, H.R., Gupta, S.K., Dikshit, A.K., 2012. An overview of sustainability assessment methodologies. Ecol. Ind. 15 (1), 281–299.

Song, Q., Zhou, N., Liu, T., Siehr, S.A., Qi, Y., 2018. Investigation of a "coupling model" of coordination between low-carbon development and urbanization in China. Energy policy 121, 346–354.

Su, M., Li, R., Lu, W., Chen, C., Chen, B., Yang, Z., 2013. Evaluation of a low-carbon city: method and application. Entropy 15 (4), 1171–1185.

Sun, C., Lin, T., Zhao, Q., Li, X., Ye, H., Zhang, G., Zhao, Y., 2019. Spatial pattern of urban green spaces in a long-term compact urbanization process—A case study in China. Ecol. Indicators 96, 111–119.

Tan, S., Yang, J., Yan, J., Lee, C., Hashim, H., Chen, B., 2017. A holistic low carbon city indicator framework for sustainable development. Appl. Energy 185, 1919–1930.

The Development and Reform Commission of Shenzhen Municipality (2013). Long-term Plan for Low Carbon Development in Shenzhen (2011-2020). http://fgw.sz.gov.cn/xxgk/ghjh/zxgh/201310/t20131016_2223234.html.

UNFCCC. (2015). Synthesis report on the aggregate effect of the intended nationally determined contributions Conference of the Parties, vol. 21.

Wang, H., Xu, J., Sheng, L., 2019a. Study on the comprehensive utilization of city kitchen waste as a resource in China. Energy 173, 263–277.

Wang, J., Cao, X., 2017. Exploring built environment correlates of walking distance of transit egress in the Twin Cities. J. Transp. Geogr. 64, 132–138.

Wang, N., Shen, R., Wen, Z., De Clercq, D., 2019b. Life cycle energy efficiency evaluation for coal development and utilization. Energy 179, 1–11.

Wang, X., Chen, L., Liu, C., Zhang, Y., Li, K., 2019c. Optimal production efficiency of Chinese coal enterprises under the background of de-capacity—Investigation on the data of coal enterprises in Shandong Province. J. Cleaner Prod. 227, 355–365.

Wu, Y., Tam, V., Shuai, C., Shen, L., Zhang, Y., Liao, S., 2019. Decoupling China's economic growth from carbon emissions: Empirical studies from 30 Chinese provinces (2001–2015). Sci. Total Environ. 656, 576–588.

Xin, L., 2011. Construction of low-carbon city evaluation index system. Statist. Decision-Making 7, 78–80 (In Chinese).

Yang, Q., Li, X., Qian, Y., Zhang, D., 2018. Technical and economic analysis of an oil shale comprehensive utilization process with solid heat carrier technology. Carbon Resourc. Convers. 1 (3), 266–272.

Yang, Y., Li, H., 2012. Research on evaluation index system of low-carbon urban development in Beijing. Sci. Technol. Manage. Res. 032 (015), 88–90 (In Chinese).

Zhou, G., Singh, J., Wu, J., Sinha, R., Laurenti, R., Frostell, B., 2015a. Evaluating low-carbon city initiatives from the DPSIR framework perspective. Habitat Int.rnational 50, 289–299.

Zhou, J., Shen, L., Song, X., Zhang, X., 2015b. Selection and modeling sustainable urbanization indicators: a responsibility-based method. Ecol. Ind. 56, 87–95.

Zhou, N., He, G., Williams, C., Fridley, D., 2015c. ELITE cities: a low-carbon eco-city evaluation tool for China. Ecol. Ind. 48, 448–456.

Zhou, N., Price, L., Yande, D., Creyts, J., Khanna, N., Fridley, D., Tian, Z., 2019. A road map for China to peak carbon dioxide emissions and achieve a 20% share of non-fossil fuels in primary energy by 2030. Appl. Energy 239, 793–819.

Zhu, L., Chen, L., Wu, X., Ding, X., 2018. Developing a greenhouse gas management evaluation system for Chinese textile enterprises. Ecol. Ind. 91, 470–477.

Zou, B., Luo, B., 2019. Rural household energy consumption characteristics and determinants in china. Energy 182 (SEP.1), 814–823.