CIB World Building Congress 2019
Hong Kong SAR, China
17 – 21 June 2019

Smart pathways of cities reducing carbon emissions in the context of China

Fan Hongqin,
Department of Building and Real Estate, the Hong Kong Polytechnic University, Hong Kong
(email: hongqin.fan@polyu.edu.hk)
Huang zhenhua
Department of Building and Real Estate, the Hong Kong Polytechnic University, Hong Kong
(email: zhenhua.a.huang@polyu.edu.hk)

Abstract

Extensive carbon emission has been widely considered as a major contributor to the severe issue of climate change, and China has been the largest carbon emitter in the world. In order to mitigate the problem of enormous carbon emission, China has launched three batches of low-carbon pilot cities and there are substantial experiences generated from the practice of low carbon city. These lessons learned from these experiences provide very important references on how to promote low carbon city development in specific cities. Therefore, this study aims at analyzing the diverse smart pathways of pilot low-carbon cities in China for providing effective insights for decision makers of cities which are going to develop low-carbon city. Firstly, this study proposes a framework for classifying cities into four types including resources cities, industrial cities, integrated cities and tourist cities. And then 34 sample Chinese low-carbon pilot cities are classified into the four groups by applying the proposed framework. Cities in different groups have different context or features and in the same group are more similar with each other. Then, the practices of low-carbon city development of these 34 sample cities are collected. And the analysis on the smart pathways of cities across different groups is conducted. This study can provide good reference for decision makers of cities when formulating effective urban development plans according to identifying which group they belong to.

Key words: Smart pathways, low carbon city, carbon emissions, and China.

1. Introduction

It is widely appreciated that extensive carbon emission has a significant impact on global warming, which pose a threat to the sustainable development of human beings. The negative influence of global warming can be seen from many aspects including economy, society and ecology (Wang et al., 2017; Annex, 2012; Schellnhuber, et al., 2013). In response to the alarming situation, many countries and organizations have advocated pursuing efforts to reduce carbon emission. For instance, the 2015 Paris Agreement put forward the long-term goals of limiting the increase of global average temperature to below 2 degrees Celsius above pre-industrial level (Höhne et al., 2017). And China has initiated three batches of low-carbon pilot cities to addressing the increasingly serious problem.

As the largest developing country in the word, China has become the largest carbon emitter and its per capita carbon emission has exceeded those of the EU (European Union) for the first time in 2013 (Chen et al., 2018; Weng and Xu, 2018). In 2014, the amount of carbon emission discharged by China has reached 9,76 billion tons, accounting for about 28.5% of total global carbon emission (Tollefson, 2015; Green and Stern, 2017; World Bank, 2014). So the low-carbon transformation of China is significant for accomplishment of global emission reduction mission. On the other hand, the Chinese government has promised at the 2015 Paris Conference on Climate Change that carbon emission of China will achieve in

or before 2030 and carbon emissions per unit GDP will decrease 60–65% compared with the carbon emission level in 2005 (Weng and Xu, 2018). Due to China's specific governance system, the national emission reduction goal needs to be distributed by central government to city-level governments.

In China, there is about more than 280 prefectural-level cities and these cities are so different in many aspects such as development stage, resource endowment, economic structure and climate. These differences determine that different types of cities should have different focus and take different pathways to promote the development of low-carbon city. This has been echoed by many other researchers. For example, Zhang (2016) suggested that local governments should sufficiently consider city's development stage, population size, resources endowment and industrial structure when transforming to low-carbon city. Since the implementation of the low-carbon strategy in China, there have generated many low-carbon city practices and learning from previous experience about how to reduce carbon emission of city is an effective approach. So far National Development Reform Commission (NDRC) of China has initiated three batches of low-carbon pilot cities and 87 of more than 280 cities have engaged in this program of low carbon pilot city. These pilots have a higher level of representatives of different locations, resources, developing phases, challenges, and opportunities in low-carbon development (Xiu et al., 2018). Therefore, it is urgent and important to set criteria for classifying these 87 cities into different types, and then systematically summarize the smart pathways of promoting low-carbon city of each types of cities. This work can provide insights for the governments of cities which is not among the 87 low-carbon pilot cities when promoting the development of low-carbon city. In other words, cities can utilize the criteria to identify which type they belong to, and then the associated smart pathways of promoting the development of low-carbon city will be obtained.

There is a body of literature that examine on the pathways of China's low-carbon city pilot from two main perspectives. One group of these focus on how an individual city promote the development of low-carbon city. For example, Bi et al. (2011), Lehman (2012), Liu et al. (2012), and Pathak et al. (2016) show the low carbon practices and lessons of Nanjing of China, Shanghai of China, Chongqing of China, and Ahmedabad of India, respectively. Another group of literature has focused on putting forward low-carbon development pathways from a national perspective. In instance, Xiu et al. (2018) selected two indicators including carbon emission per capita and GDP per capita to categorize the 36 cities from China's low-carbon pilot project into four types to reveal their low-carbon development pathways. And these four types are leading cities, developing cities, latecomer cities, and exploring cities. By combining Chinese national conditions with foreign countries' advances experience, Yang and Li (2013) proposed several pathways of developing low-carbon cities from the aspects of energy use, transportation, housing, employment and service facilities, green infrastructure, water resources use and waste disposal. Wang et al. (2015) presented the status of the low-carbon city pilot programme in China and summarized that policies taken by the government of China include improving energy efficiency, applying renewable energy, adjusting sector structure, and increasing carbon sequestration capacity. Su et al. (2016) reviewed the low-carbon practice in Chinese cities, which include setting up urban low-carbon development planning, establishing low-carbon demonstrative areas, focusing on such specific fields as sustainable energy system, ecological industry, green transportation, and green building. Liu and Qin (2016) conducted a review on China's current low-carbon city policies.

Through literature review, this study finds several gaps in the existing study: (1) for some study, which select an individual city as case to reveal its low-carbon city development measures, it is too narrow to just outline some practice. They fail to present a holistic solution for establishing a low-carbon city. (2) as for these, which devoted effort to summarize and present the practice of low-carbon city development in China form a national perspective, they did not classify cities into different groups as well as summarize the practice for each group. Therefore, the aim of this study is to classify low-carbon pilot cities of China into four groups and summarize and present the smart practice of each city group.

Following this introduction section, section 2 shows and explains the methodology of this study in details. Next, the results of this study are presented in section 3. Afterwards, section 4 provides the discussions of the analysis results. Finally, section 5 concludes this research work.

2. Research methodology

In order to achieve the aim of this study, this study proposes a methodology which comprised of two procedures. Firstly, a framework for city classification are established. And then, this research will apply the framework to classify Chinese low-carbon pilot cities into different groups, and subsequently summary and analysis on the smart pathways adapted by each city group will be conducted.

2.1 Development of a framework for city classification

Chinese Academy of Sciences has classified Chinese cities into four groups including resources cities, industrial cities, integrated cities and tourist cities, and also presented the level of carbon emission of each group, as shown in table 1 (Long et al., 2010). It is obvious from table 1 that these four groups are significantly different in low-carbon performance, because the four groups are different in many aspects such as economic level, industrial structure and energy structure. However, the classification criteria of Chinses cities are not available. So this study sets reasonable criteria for classifying Chinese cities into these four groups.

Table 1 The carbon emission levels of China's four types of cities

	Resources Cities	Industrial Cities	Integrated Cities	Tourist Cities
Per capital carbon emissions in urban area (T/P)	16.22	15.31	15.01	7.74
Per square kilometer carbon emissions in urban area (10^4 t/km^2)	16.1	1.57	1.93	0.69
Per GDP carbon emissions in urban area (t/10^4Yuan)	4.17	1.91	2.54	1.65

(Long et al., 2010)

In the policy paper *National sustainable development plan for resource-oriented cities (2013-2020)* published by *the State Council of China*, 262 of 661 cities in China are defined as resources cities, so this study also defines these 262 cities as resources cities. Currently, there is not accessible methods for the definition of industrial cities, integrated cities and tourist cities. This study proposes a framework for defining what are industrial cities, integrated cities and tourist cities, as shown in Figure 1. And the framework is explained as follows:

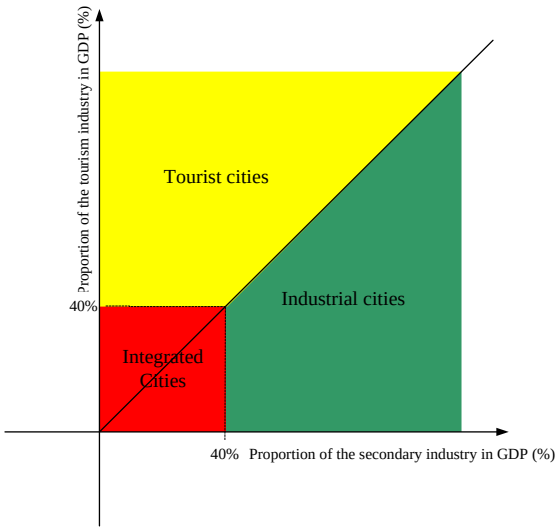

Fig. 1 The framework for city classification

(1) Integrated cities: proportion of the secondary industry in GDP and proportion of tourism industry in GDP are lower than 40%.
(2) Industrial cities: proportion of the secondary industry in GDP and proportion of tourism industry in GDP are higher than 40%, and proportion of the secondary industry in GDP is higher than that of tourism industry in GDP.
(3) Tourist city: proportion of the secondary industry in GDP and proportion of tourism industry in GDP are higher than 40%, and proportion of the secondary industry in GDP is lower than that of tourism industry in GDP.

2.2 Summary and analysis on the smart pathways adopted by each city group

Literature review is a common method used for summarizing and analyzing the development pathways of cities (Liu and Qin, 2016). After classifying the low-carbon pilot cities in China into four groups according to the criteria established in section 2.1, a comprehensive summary and analysis on the smart pathways adapted by each city group is conducted by literature review.

3. Smart pathways of developing low-carbon city in China

3.1 Pilot cities

In this study, a sample of 34 low-carbon pilot cities are selected to support the analysis on the smart pathways of developing low-carbon city in China. By now, National Development Reform Commission (NDRC) of China has initiated three batches of low-carbon pilot provinces or cities to explore feasible pathways of developing low-carbon cities which can be replicated on a larger scale. The third batch of pilots just began, which is launched in 2017. Therefore, this study focuses on the initial two batches including 6 provinces, 4 provincial-level municipalities, 32 prefecture-level cities, which were implemented in 2010 and 2012, respectively. In addition, cities and provinces have many different unique

features. As a result, this study chooses 34 cities in the initial two batches to establish the case base, as shown in Figure 2. It is obvious that these 34 low-carbon pilot cities are located in different regions of China, representing the majority of inhabitation areas with different features.

Fig. 2 Sample low-carbon city

3.2 Data collection

The data about the two indicators used for classifying low-carbon pilot cities, namely, proportion of the secondary industry in GDP and proportion of tourism industry in GDP are collected from *China city statistical Yearbook 2017* published by *National Bureau of Statistics of China*, and *Statistical communique on national economic and social development in 2017* published by the government of these 34 sample low-carbon cities.

3.3 Classification results of low-carbon pilot cities

According to the policy paper *National sustainable development plan for resource-oriented cities (2013-2020)* published by *the State Council of China* and the framework for city classification established by this study, the 34 sample low-carbon pilot cities can be classified into four groups, as shown in Table 2.

Table 2 Classification results of low-carbon pilot cities

Type	City
Resources cities (10)	Jincheng, Hulunbeir, Jilin, Chizhou, Nanping, Jingdezhen, Ganzhou, Guangyuan, Yanan, Jinchang
Industrial cities (14)	Zhenjiang, Ningbo, Wenzhou, Xiamen, Nanchang, Qingdao, Wuhan, Chongqing, Zunyi, Tianjin, Shijiazhuang, Baoding, Suzhou, Huaian
Integrated cities (7)	Beijing, Shanghai, Hangzhou, Guangzhou, Shenzhen, Kunming, Urumchi
Tourist cities (3)	Qinhuangdao, Guilin, Guiyang

3.4 Summarizing the smart pathways of low-carbon development in China

In order to identify the existing low-carbon city development pathways in the context of China. The research team has identified many typical policy and regulation papers relevant to the practice of low – carbon in the context of China. As a result, 49 low-carbon city pathways are obtained and categorized in 8 groups, as shown in Table 3.

Table 3 Low-carbon city pathways selected by this study

Practice category	Low-carbon city pathway
Develop low-carbon economy (P1)	Promote the development of low-carbon industry (P11) Promote the upgrading of traditional industries (P12) Develop tertiary industry (P13) Develop low-carbon agriculture (P14) Shut down heavy energy-consumption enterprises (P15) Promote development of photovoltaic industry (P16)
Optimize the energy structure and Improve energy efficiency (P2)	Increase the utilization proportion of natural gas (P21) Promote the development of hydropower projects (P22) Promote the development of wind-power projects (P23) Promote the exploitation and utilization of biomass energy (P24) Develop the projects of landfill gas recovery and power generation (P25) Lunch cogeneration power plants (P26) Promote the utilization of solar power (P27) Promote the exploitation and utilization of renewable energy and new energy (P28) Promote energy-saving and emission reduction in industry (P29)
Carry out demonstration projects (P3)	Low-carbon industry demonstration (P31) Low-carbon building demonstration (P32) Low-carbon transportation demonstration (P33) Low-carbon enterprise demonstration (P34) Low-carbon industrial park demonstration (P35) Low-carbon community demonstration (P36) Low-carbon town demonstration (P37)
Increase carbon-sink (P4)	Increase forest carbon-sink (P41) Promote urban afforestation construction (P42) Increase wetland carbon-sink (P43)
Develop low-carbon building (P5)	Promote green and energy-saving building (P51) Promote energy-saving building standards (P52) Promote new energy-saving building materials (P53) Promote ground-source heat pump technology (P54) Install Solar photovoltaic systems on the roof of the building (P55) Reduce energy consumption of government office buildings (P56) Carry out energy-saving upgrading in existing buildings (P57) Promote the utilization efficient energy-saving lighting system (P58)
Develop low-carbon transportation (P6)	Prioritize the construction public transportation (P61) Construct urban rail transit (P62) Promote the use of energy-saving and environment-friendly vehicles (P63) Construct intelligent transportation network system (P64) Eliminate high-polluting vehicles (P65)

Develop low carbon life (P7)	Guide the public to use green forms of transport (P71) Develop low-carbon consumption habits (P72) Raise residents' awareness of low-carbon life (P73) Collect and disposal household garbage (P74)
Low-carbon city management (P8)	Establish low-carbon product certification (P81) Establish a low-carbon development research center (P82) Establish a statistical management system for carbon emission (P83) Carry out trials for trading carbon emission rights (P84) Establish a performance evaluation mechanism for low-carbon development (P85) Making regulations on low-carbon development (P86) Making low-carbon city development plan (P87)

In Table 3, pathways of low-carbon city development are summarized from a national perspective. Next, this study summarizes these pathways for the four types of cities including resources cities, industrial cities, integrated cities and tourist cities. Some pathways are only adopted by few cities in certain city type. In this study, if a pathway is adopted by more than 80% of cities, we considered this pathway as a smart pathway. The smart pathways of each type of cities are shown in Fig. 3, Fig. 4, Fig 5 and Fig 6. The two axes in each figure represent respectively the low-carbon city smart pathway and the adoption frequency of low-carbon city pathway (AF). AF can be measured by the proportion of cities adopting one certain pathway in each city group.

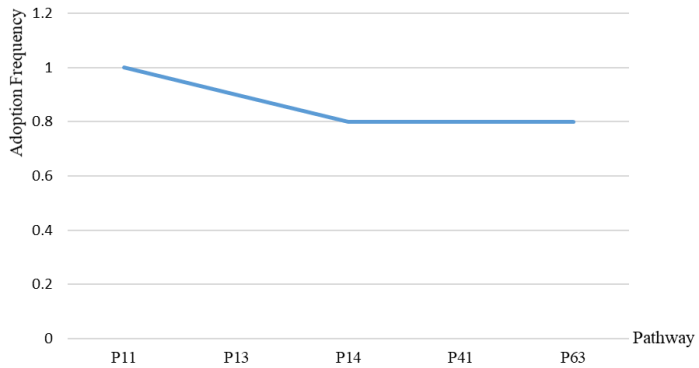

Fig. 3 The smart low-carbon development pathways for resources cities

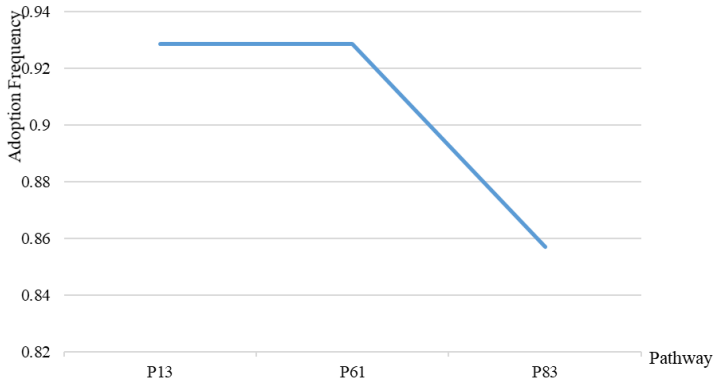

Fig. 4 The smart low-carbon development pathways for industrial cities

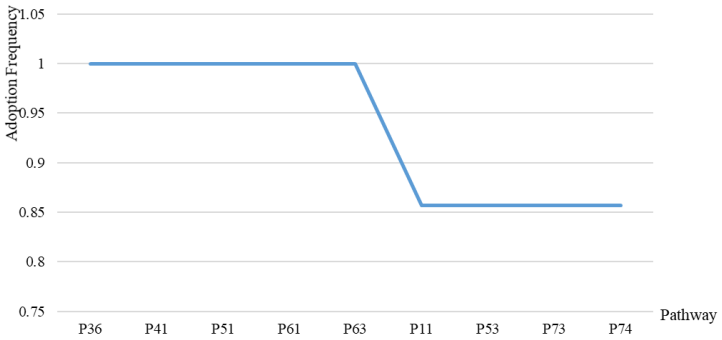

Fig. 5 The smart low-carbon development pathways for integrated cities

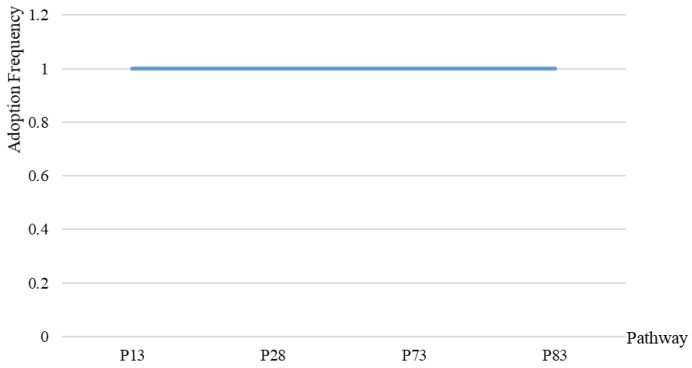

Fig. 6 The smart low-carbon development pathways for tourist cities

4. Discussion

In this section, the analysis on the smart pathways for low-carbon city development of the four types of cities are conducted.

4.1 Smart pathways of resources cities

This research takes the definition of resources cities in the policy paper *National sustainable development plan for resource-oriented cities (2013-2020)* published by *the State Council of China* as reference, which defines resources cities as these whose leading industries are mineral, forest and other natural resources exploitation and processing. In Chinese resources cities, industrial development still highly depends on natural resources, the proportion of extractive industry in secondary industry is more than 20%, and modern manufacturing and high-tech industries are in the early stage. In some resources cities, the situation is worse where the development speed is so fast so that the comprehensive utilization level of natural resources is low and the ecological environment is seriously damaged. As a result, the carbon emission of resources cities is pretty extensive.

In referring to Fig.3, the smart pathways of resources cities for low-carbon development include promoting the development of low-carbon industry (P11), developing tertiary industry (P13), developing low-carbon agriculture (P14), increasing forest carbon-sink (P41), promoting the use of energy-saving and environment-friendly vehicles (P63).

As mentioned above, extractive industry holds a very great proportion in the economy of resources cities. In combination with the industrial base and development orientation, resources cities should actively develop modern service industries, which are commonly considered as low-carbon industries. Relying on the advantages of resource products, resources cities can build a number of regional logistics centers for coal, iron ore, crude oil, wood and other resource products, as well as important industrial products such as steel, building materials and chemicals. These cities can also vigorously develop custody services, engineering and management consulting for the resource industry. On the basis of effective protection of resources, resources cities should encourage forest industry cities with good ecological environment to develop leisure tourism, support cities with rich natural landscape resources to develop natural scenery tourism, promote cities with long industrial history to develop characteristic industrial tourism, and support cities with concentrated revolutionary sites to develop history tourism.

4.2 Smart pathways of industrial cities

In industrial cities, industry consumes the largest percentage of energy and accounts for most of the total carbon emission. From a national perspective, 90% of energy takes place in the industrial sector (Lin and Liu, 2010), and 42–44% of the total carbon emissions every year from 1992 to 2012 was emitted from manufacturing industry (Tian et al., 2018). This is mainly because coal is still the dominant fuel for electricity and heat generation at present.

It can be seen from Fig.4, the smart pathways of industrial are developing tertiary industry (P13), prioritizing the construction public transportation (P61), establishing a statistical management system for carbon emission (P83).

Compared with secondary industry, tertiary industry is more low-carbon and environmentally friendly such as tourism, logistics, e-commerce and finance. Several specific measures can be taken to help industrial cities fulfill the process of converting to low-carbon cities. These measures include setting up special funds to cultivate emerging and strategic industries, and facilitating the elimination of backward production. Prioritizing the construction public transportation has a significant impact on the use of private cars, which is a great emitter of carbon emissions in city. The commonly adopted actions for constructing public transportation are new energy vehicle promotion and application, building urban walking and bicycle transport system, building bus rapid transit and rail transit, and popularizing new energy vehicles through fiscal subsidies. A reliable statistical management system for carbon emission can plays a key role in tracking and calculating the amount of carbon emission, which can help decision makers formulate effective policies.

4.3 Smart pathways of integrated cities

In integrated cities, the proportion of the secondary industry in GDP and that of tourism industry in GDP are lower than 40%. There are 14 low-carbon pilot cities belonging to integrated cities. For these cities, industries and tourism do not play a dominate role in their economy. So the measures for reducing carbon emissions should be taken in all city sectors.

In referring to Fig.5, the smart pathways of integrated cities for low-carbon city development include low-carbon community demonstration (P36), increasing forest carbon-sink (P41), promoting green and energy-saving building (P51), prioritize the construction public transportation (P61), promoting the use of energy-saving and environment-friendly vehicles (P63), promote the development of low-carbon industry

(P11), promoting new energy-saving building materials (P53), raising residents' awareness of low-carbon life (P73), and collecting and disposing household garbage (P74).

4.4 Smart pathways of tourist cities

In this study, we define cities whose tourist industries dominate their economies as tourist cities. Tourism is generally viewed as a highly consumptive industry with a substantial share of destinations operating at less desirable eco-efficiency values than the global average (Patterson and Bastianoni, 2007). Tourism industry involves a high cost of resource consumption and a rapidly increasing consumer demand. It is reported that to some extent the increasing scale of tourism leads to energy supply shortage, carbon emissions increase, climate change and other global problems of resources and environment.

Fig. 6 shows that smart pathways of tourist cities for low-carbon city development are developing tertiary industry (P13), promoting the exploitation and utilization of renewable energy and new energy (P28), raising residents' awareness of low-carbon life (P73), establishing a statistical management system for carbon emission (P83), and promoting the development of low-carbon industry (P11). Tourist cities can take these pathways to develop low-carbon tourism, which can contribute to the reduce of carbon emission. Some evidences have proven that these smart pathways are effective for tourist cities for transforming from high emitters to low emitters. For example, many countries have launched low-carbon hotels such as Ton Sai Bay Hotel in Koh Samui, Thailand and the luxury and romantic Banyan Tree Resort in Bintan, Indonesia (Can and Hongbing, 2011).

5. Conclusions

Extensive carbon emissions are a major contributor of the severe issues of climate change and China has become the largest carbon emitter. In order to mitigate the problem of climate change, Chinese government has initiated three batches of low-carbon pilot cities, which are located in different regions of China, representing the majority of inhabitation areas with different features. The implementation of low-carbon pilot city program has generated lots of experiences about how to promoting the development of low-carbon city. This study proposes a framework for classifying these 34 low-carbon pilot cities into 4 groups including resources cities, industrial cities, integrated cities and tourist cities. And then though the method of literature review, this study summarizes the existing pathways adopted by 34 low-carbon pilot cities. Furthermore, based on the list of low-carbon development pathways, this study identifies smart pathways for these four types of cities.

The framework established by this study is a useful tool, which can help local governments identify which type of city they are. After this step, the corresponding smart pathways for developing low-carbon city will be obtained, which can provide useful insights for decision makers. On the other hand, this framework for classifying cities can be taken as reference by other researchers when there is a need to classify cities into different groups for solving other urban-related problems.

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