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Development path of Chinese low-carbon cities based on index evaluation

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Abstract

This work takes the 36 cities from China's low-carbon pilot project as the research object and uses the carbon emission per capita and GDP per capita to categorize the 36 cities into four types to reveal their low-carbon development status; these four types are leading cities, developing cities, latecomer cities, and exploring cities. On the basis of an index system that quantitatively describes low-carbon development, this research analyzes the characteristics, development trends, and low-carbon development pathways of the four types of cities. According to the present situation and objectives of national emissions and considering the differences in development stages, challenges, and opportunities for each type of the city, this research presents recommendations for the low-carbon roadmap and the medium- and long-term (by 2030) emission trend routes of different types of regions in China.

Keywords: City; Low-carbon development; Index evaluation; Development path

1. Introduction

China accounts for about one-third of world's total greenhouse gas (GHG) emissions and is responsible for more than half of the world's increase in GHG emissions in the last 10 years (IEA, 2016). China presented its GHG control targets in its Intended Nationally Determined Contribution to achieve its peak CO_2 emissions around 2030 and is making its best efforts to peak early and to achieve other targets related to green, low-carbon development (CG, 2015).

City[1] is one of the key players in realizing GHG control targets. To promote the implementation of the target to control GHG emissions and explore the modes and paths of low-carbon development at the city level with different conditions and characteristics, China launched the low-carbon provinces and cities pilot project in July 2010 and approved three batches of a total of 87 low-carbon pilot areas, including 81 cities and 6 provinces. These pilots serve as representatives of different locations, resources, developing phases, challenges, and opportunities in low-carbon development. Therefore, a necessary task is to look into the current status of their carbon emission level, characteristics, developing trend, and challenges to illustrate low-carbon development strategies for distinct regions all over China.

The index system approach is a common methodology that is used to analyze and evaluate development at the city level both for policymaking and research. The core of establishing an indicator system is to determine the specific content and assessment standards. In China, some ministries and commissions have set up a series of index systems relevant to the concept of a low-carbon city, such as the National Ecological Garden City Standard (MOHURD, 2016), Evaluation Index System of New Energy Demonstration City (NEA, 2012), Construction Target System of National Ecological Civilization Demonstration Zone, Statistical Index System for Climate Change (NDRC, 2013), Green Development Index System (NDRC, 2016), and Evaluation Target System of Ecological Civilization Construction (NDRC, 2016).

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[1] In this study, the concept of carbon emission means direct CO_2 emission related to energy. CO_2 emission by external power is not included.

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Some influential research institutions in China have also explored evaluation index systems for low-carbon cities. The China Green Development Indicators formulated by Beijing Normal University established 57 indicators that are applied to 30 provinces and 100 cities (BNU, 2016). The three-level index system of "economic growth greening degree, potential bearing capacity of resource environment, and governmental policy support" as primary indicators highlights the urgency of China's green development. Tsinghua University, Columbia University, and McKinsey & Company regard basic needs, resource efficiency, environmental cleanliness, built environment, and commitment to sustainability as the framework and have formulated sustainable urban development indicators (CG, 2015). Eighteen of these indicators have been established and applied to 113 cities whose construction of environmental protection should be strengthened, as mentioned in the 11th Five-Year Plan of China. The Chinese Academy of Social Sciences took economic transformation, social transformation, low-carbon facilities, low-carbon resources, and low-carbon environment as the framework and formulated a comprehensive index system for China's low-carbon urban development evaluation (Zhu and Liang, 2012), and 10 indicators have been established and applied to 110 cities in China. The Chinese Academy of Sciences published a series of reports on China's sustainable development, including a sustainable development capability index system with municipalities directly under the central government, provinces, and autonomous regions as the main targets. A comprehensive evaluation was conducted through 45 elements and 233 indicators (Huang and Wang, 2014).

Internationally, several index systems related to the low-carbon city include the following: the international standard Sustainable City Development Index System defines and establishes methodologies for a set of indicators to steer and measure the performance of city services and quality of life (ISO, 2014); the Urban Indicators formulated by the United Nations Human Settlements Programme regard housing, social development, poverty eradication, and environmental management as the framework (UN-HABITAT, 2009); and the European green city indicators and Asian green city indicators formulated by the British Economist Intelligence Unit and Siemens (2011) take CO_2 emissions, energy, construction, transportation, water, waste and land use, air quality, and environmental governance as the main framework (Unit and Siemens, 2011).

From the above practices and researches, the index analysis is proved to be an effective approach to quantitatively describe, compare and rank a group of cities' development level with various parameters. The indicator amount of the above practices and researches are basically 20–100, with social and economic growth, policy system, and urban form usually taken into consideration. However up to now, there is still no official index system for the evaluation of Chinese city's low-carbon development and indicators for the determination of a low-carbon city are still under discussion, meanwhile the international experience for low-carbon city evaluation is not quite suitable for China's own characteristics. There are several other inadequacies from the existing practices and researches. First, the various local conditions in China are usually neglected and there is barely any classification analysis. Second, most of the existing index systems pay attention to historical value of the indicators and future trend of distinct cities is seldom analyzed. Third, due to public data resources limitation, there is always a gap of data to carry out analysis, especially when an index system has more than 20 indicators.

This study aims to propose low-carbon pathways for Chinese cities with distinct conditions, on a basis of index system approach. Considering representativeness in geography distribution, size and developing phase, we take the 36 cities in the first and second low-carbon pilot batches as the research object. The following sections are organized as following. Section 2 sets up an index system that could reflect the demand of low-carbon development for Chinese cities and categorize the pilot cities according to value of key indicators. Section 3 assesses the status, trend and challenges of low-carbon development for each type of cities by quantitative and qualitative analysis with index system analysis and case study approach. Section 4 summarizes the main findings.

2. Research methodology

2.1. Establishment of key indicators

On the basis of the research foundation of both the international and domestic indicator system experiences and a literature review of relevant theoretic research combined with the current unique situation of China, the indicator system should apply to the following principles:

- Scientific: It should comprehensively and objectively reflect low-carbon development and facilitate the gradual establishment of a low-carbon development model that can adapt to China's unique conditions.
- Universality: It should be simple and result-oriented rather than detailed to adapt to all regions.
- Operability: Data for the system should be available, and the information should be accessible.

By 2020, China is expected to have built a moderately prosperous society in all respects, as well as a prosperous, democratic, civilized, harmonious, and beautiful modern socialist country; and by 2035 China is committed to basically realize socialist modernization (Xi, 2017). The key driver for the carbon emission increase in China is GDP growth during the country's fast industrialization and urbanization process. On the basis of the above analysis together with integrated research purposes and data accessibility, we selected the following index to construct an evaluation and analyzed low-carbon pilot cities:

- **Carbon emission per capita**: Total energy-related CO_2 emissions of a region/permanent resident population of the region. This is the key indicator that represents a city's emission level.
- **Carbon emission per unit of GDP**: Energy-related CO_2 emissions per unit of GDP. This indicator reflects the

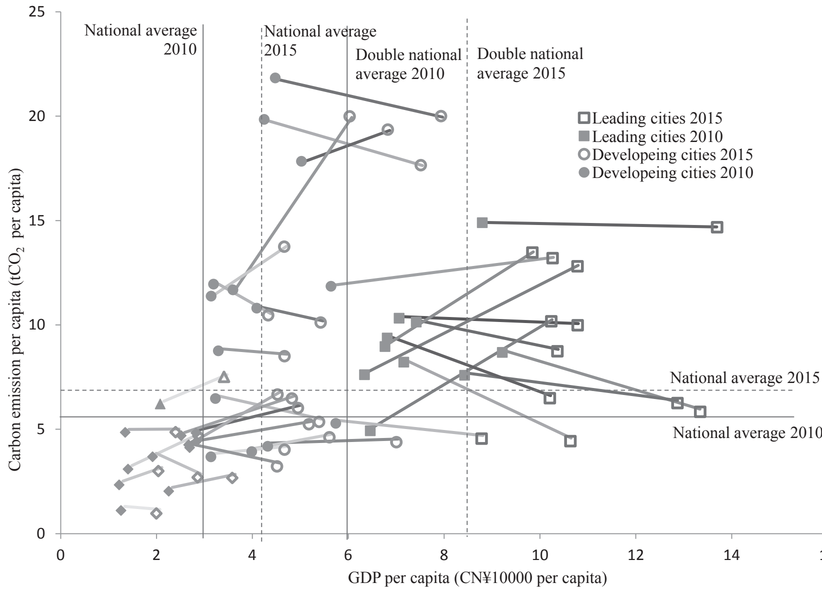

Fig. 1. Key indicators for low-carbon pilot cities in 2010 and 2015.

carbon productivity and efficiency of the economy. China presented its GHG control targets in terms of decrease in carbon emission per unit of GDP, that is, a 17% decrease in 2015 compared with the 2010 level and a 40%–45% decrease in 2020 compared with the 2005 level.

- **GDP per capita**: Gross regional domestic product/permanent resident population of the region. This is the key indicator that represents economic level.
- **Population**: The population in a region. This indicator is presented according to municipal level, including both urban and rural areas.
- **Urbanization rate**: The proportion of permanent urban residents in a region to total permanent residents in the region. This indicator reveals the stage of urbanization of a certain city.
- **Proportion of tertiary industry**: Share of tertiary industries in total GDP. This indicator reveals the stage of industrialization of a certain city.
- **Main functional zone**: The city's definition in the national and regional main functional zone. China is categorized into four zoning types: optimal development zone, major development zone, restricted development zone, and prohibit development zone. This indicator decides a city's future development orientation.

This research collected low-carbon development index data based on the city's or province's statistical yearbooks, statistical bulletins from published documents, and their self-assessment reports on low-carbon pilot progress.[2]

2.2. Categorizing cities based on key indicators

Two key indicators are used to evaluate the low-carbon development at the city level. One is GDP per capita, which serves as a quantitative indicator to measure economic development and people's living standard. The other one is emission per capita, which reflects emission level and low-carbon status. On the basis of the two indicators, the pilot cities can be categorized into four types.

- Leading cities: GDP per capita exceeds twice the national average;
- Developing cities: GDP per capita exceeds the national average but is lower than twice.
- Latecomer cities: GDP per capita is below the national average, but emission per capita is higher than the national average;
- Exploring cities: GDP per capita and carbon emission per capita are below the national average.

The cities are categorized according to 2010 and 2015 data, and the results are shown in Figs. 1 and 2, and Table 1 (NBS, 2010, 2015; NCSC, 2018).

3. Characteristics of the cities

This section analyzes the challenges, pathways, and key measures for low-carbon development for the four categories through indicator analysis and case study approaches.

3.1. Description and comparison of indicators

According to the index system and categorization results, we analyze the low-carbon development status, characteristics, and development stage of each category. Fig. 3a–e shows the

[2] Internal material, submitted to National Development and Reform Commission in 2016.

Fig. 2. Geography distribution of the cities in 2015.

Table 1
City categories based on key indicators.

Type	City (2015)
Leading cities (12)	Suzhou, Shenzhen, Guangzhou, Tianjin, Zhenjiang, Beijing, Shanghai, Wuhan, Qingdao, Hangzhou, Ningbo, Xiamen
Developing cities (17)	Jincheng, Urumqi, Nanchang, Jiyuan, Hulun Buir, Yan'an, Jilin, Kunming, Chongqing, Huai'an, Guiyang, Wenzhou, Shijiazhuang, Jincheng, Jingdezhen, Nanping, Qinhuangdao
Latecomer cities (1)	Chizhou
Exploring cities (6)	Guilin, Zunyi, Baoding, Daxing'anling, Guangyuan, Ganzhou

comparison of the other five indicators among the four categories, and they are illustrated in detail in Table 2 (NBS, 2010, 2015; NDRC, 2016).

3.2. Case studies

3.2.1. Case study of a leading city: Beijing

As Chinese capital and an international metropolis, Beijing is one typical leading city with a population of 21.7 million, urbanization rate of 86%, and tertiary industries share of 80%. Beijing has shown a slow growth trend both in its population and urbanization rate in the past five years (Fig. 4a) (BMBS, 2015). Defined as China's political center, cultural center, international communication center and S&T innovation center, Beijing and has already been on track of a transition of service-dominated industrial structure. Primary and secondary industries accounted for slowly decreasing proportions, and the proportion of the primary industry was almost zero in 2015. The city had also entered a period of stable industrial structure and a late stage of industrialization (Fig. 4b).

Regarding carbon emissions, both carbon emission per capita and carbon emission per unit of GDP show a declining trend in 2010–2014 and a rise in 2015 again (Fig. 4c). Carbon emission for industry and construction has already reached the peak value in 2010. Along with the continued improvement of people's living standards in the future, the resulting continuous growth in transportation, building, and daily life will be the most important driver of carbon emission growth. Thus, the main challenge in total GHG control for Beijing is to reach a stable peak by control of fast GHG emissions from living and realize a continuous decrease in industry.

Leading cities have the characteristics of large population, advanced economic efficiency, with higher urbanization rate and higher share of tertiary industry. Although this type of cities is not the highest in terms of carbon emission per capita, the control of total carbon emission amount is the most urgent challenge for them. The reason is that the leading cities are economically advanced regions in China and will be the first batch to finish urbanization and industrialization. Therefore, greater contribution should be made by this category of cities in China's realization of its peak emission target, leaving more room for carbon emission growth along with future development of other regions. Thus, this category of cities should also be the first batch to reach the carbon emission peak. Additionally, leading cities have reached a relative higher living standard and the pursuit of environmental quality is greater than that of other types. However the leading cities are mostly located in the eastern coastal areas and are also the areas that are worst hit by China's environmental problem, especially haze, in recent years. Achieving environmental governance

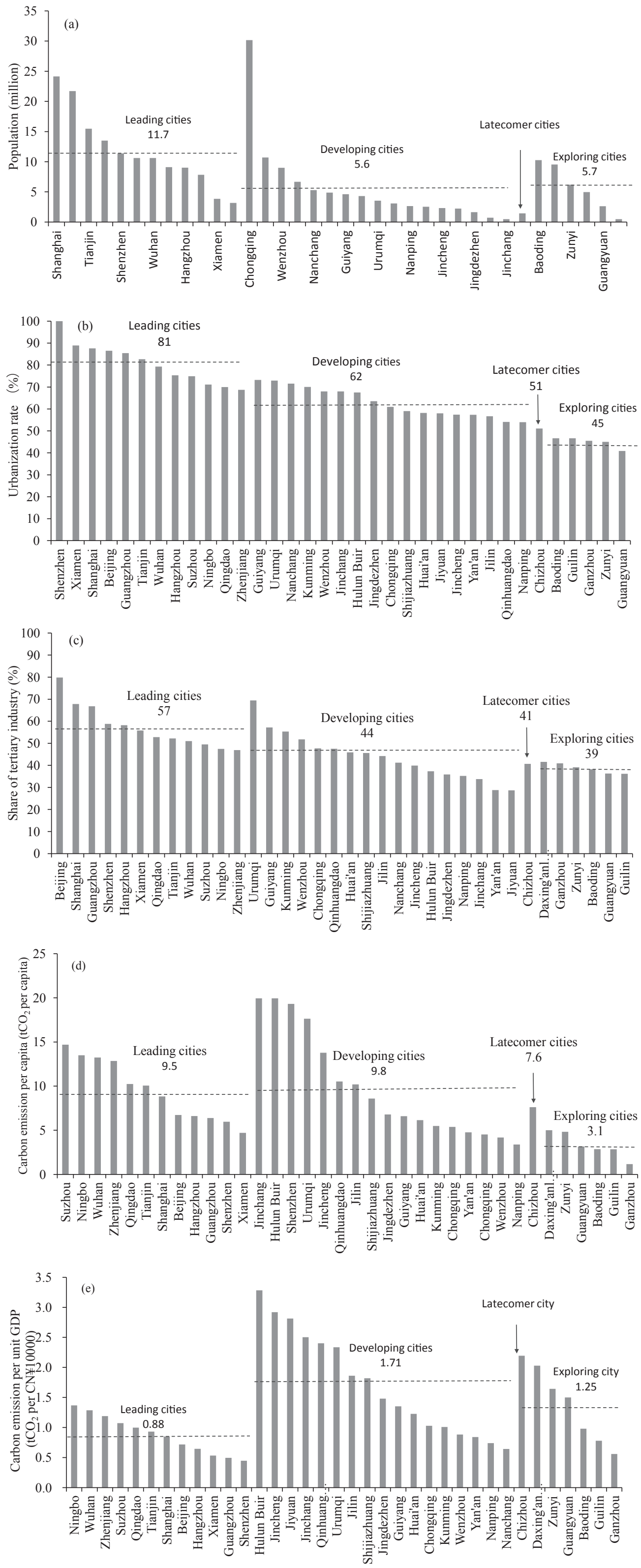

Fig. 3. Population (a), urbanization rate (b), proportions of tertiary industry (c), carbon emissions per capita (d), and carbon emission per CN¥10000 (e) of pilot cities in 2015 (The imaginary line in the figure shows the mean value of corresponding indicator for each type of cities).

and improving air quality as soon as possible are both people's concern and an urgent need in these cities, thus GHG control is also attached great importance due to its co-benefit with the environmental pollutants control.

Considering the low-carbon development paths, the leading cities should make an effort to improve urban environment by adjusting urban planning and infrastructure improvement, advocating the formation of low-carbon lifestyles and consumption patterns, improving energy efficiency in construction and transpiration, and raising the utilization ratio of clean energy.

3.2.2. Case study of a developing city: Jincheng

Jincheng, situated in northern China, Shanxi province, is a provincial base for iron casting, thermal power, and animal husbandry. It has abundant natural resources such as coal and iron. It was categorized as a developing city in both 2010 and 2015, being a medium-sized city with more than 2 million residents and a slow population growth with an average growth rate of 0.3% during 2010—2015 (Fig. 5a). Although its urbanization rate is still lower than the average urbanization rate in leading cities, it shows a fast growing trend, with 33,000 residents shifting from the countryside to the urban area annually. The carbon emission per unit of GDP exhibited a continuous decline during 2010—2015 and was 2.89 t $CO_2(CN¥10000)^{-1}$ in 2015, which is more than three times the average of leading cities and 70% more than the average of developing cities. Although its carbon emission per capita seems to decline slightly, it reaches as high as 13.6 t CO_2 per capita in 2015, which is nearly twice the national average (Fig. 5c). The pressure of GHG control for Jincheng is quite urgent. The high emission level is due to its industrial structure. Heavy industry such as coal industry, ironing industry, power industry, and chemical industry dominates in Jincheng. It is an important regional power source and about 80% electricity production was delivered outward in 2015. Its share of tertiary industry is much lower than the national level in 2015 (50.5%) and second industry takes account for 55.4% (Fig. 5b). Adjusting the industrial structure and upgrading existing industries are crucial.

For this category of cities, economic development is still a priority. Developing cities are the second echelon in economy in China and thus should be correspondingly the second batch to reach carbon emission peak around 2025. However, these cities have rather high emission intensity, in terms of per capita and per GDP, since many cities in this category have an industrial structure dominated by heavy industries and energy industry. Under the ongoing rapid industrialization and urbanization, the conflict between the control of GHG emission and economic development is rather serious for this category. With the further increase in urbanization rate in the future, a large amount of construction of infrastructure will take place. Meanwhile during the process of development, carbon emission from transport, building, and daily life will also potentially increase fast. Therefore, in view of developing cities, the dual constraints of emission intensity and total emission

Table 2
Comparison of indicators among four types of cities (2015).

Description	Leading cities	Developing cities	Latecomer cities	Exploring cities
Population	This category has the largest average population (11.7 million), and all leading cities have a population larger than 3 million. The unbalanced regional development in China means that advanced regions are more attractive places in which people can settle.	The population varies greatly among developing cities, from 0.5 million to 30 million.	Chizhou is a medium-sized city in China.	The population varies greatly among the exploring cities, from 0.5 million to 9.5 million.
Urbanization rate	The urbanization rate is far higher than that of other categories. The urbanization rate in most of the leading cities is more than 70%, with an average of 81%, and which is as high as 100% in Shenzhen. This indicates that most leading cities have entered the late urbanization stage.	The average urbanization rate of developing cities is 62%, showing an ongoing urbanization process in this category.	The urbanization rate of Chizhou is 51%, revealing it is in a middle stage of urbanization process.	The average urbanization rate for exploring cities is 45%, the lowest among the four types. Cities in this category are still in the early-middle stage of urbanization with potential large amount of increase.
Share of the tertiary industry	The share of the tertiary industry is remarkably higher than that of other types, with a gap of 13% compared with the average proportion in developing cities. Most cities in this category have entered the post-industrialization stage.	The share of the tertiary industry varies among developing cities along with their distinct industrial structure. Although the average is 44%, this value of several developing cities is quite low. For example, the tertiary industry share of Jiyuan, a city in northern China with a dominant heavy industry, is less than 30%.	The share of the tertiary industry of this category is 40%, which is 10 percentage points lower than the national average.	The proportion of the tertiary industry is the lowest, revealing that it is still in the early stage of industrialization.
Carbon emission per capita	The average carbon emission per capita is 9.48 tCO_2, about one-third higher than the national average. Looking at the developing trend, this indicator in most leading cities has entered a plateau or a declining stage. Seven of the 12 cities have shown a drop in carbon emission per capita compared with that in 2010 (Fig. 1).	Carbon emission per capita of developing cities is the highest among the four categories. Seen from the compared data of 2010 and 2015, carbon emissions per capita of developing cities show an obvious increase, and only 5 of the 17 cities present a decline.	Carbon emission per capita of latecomer cities is relatively low. With economic increase and constant progress in industrialization and urbanization, carbon emissions in these regions will continue to increase.	Carbon emission per capita is the lowest. From 2010 to 2015, the increase in carbon emission per capita was obvious in exploring cities.
Carbon emission per unit GDP	The average of carbon emission per unit GDP is the lowest among the four types of cities, showing the highest carbon productivity.	Carbon emission per unit GDP is twice that of the leading cities. This finding is consistent with the indicator of tertiary industry share, namely, that the cities with high carbon emission per unit GDP usually have a low share of tertiary industry.	Carbon emission per unit GDP is the highest. At present, latecomer cities are undergoing industrialization, and the development pattern is relatively extensive.	Carbon emission per unit GDP is relatively low, which is mainly caused by an underdeveloped economy and incomplete urbanization.
Functional zone	Mostly situated in the optimal development zone, which features important hubs and thoroughfares to the sea, large ports to open up to the world, national science and technology innovation and technology research and development centers, bases for modern service industry and high-tech industry, demonstration areas for resource-saving and environment-friendly society construction, world-class large urban agglomerations and economic centers, etc.	Most cities in this category are major development zones, defined as demonstration zones for the transformation of the resource-based economy, the pilot area of the reform and development of private economy, an important base for new energy, equipment manufacturing industry, and high-tech industry, center for regional logistics, commerce, and trade circulation, and financial service, important natural and cultural tourist center, etc.	Chizhou is defined as a major development zone along with restricted development zone, according to Anhui province's main functional zoning.	Dominated by major and restricted development zones (key ecological functional areas), some cities in this category are included in the national forest protection directory.

amount should be applied, and carbon emission in all sectors including industry, construction and living should be attached importance to.

Developing cities should focus on their local conditions and seek low-carbon transition paths. In the process of urbanization, they should emphasize low-carbon characteristics, focus on the layout of urban planning and functional zoning, undertake infrastructure construction for low-carbon transport, and build energy-efficient and low-carbon buildings. While improving living standards, such cities should guide and promote the formation of low-carbon lifestyles and consumption patterns.

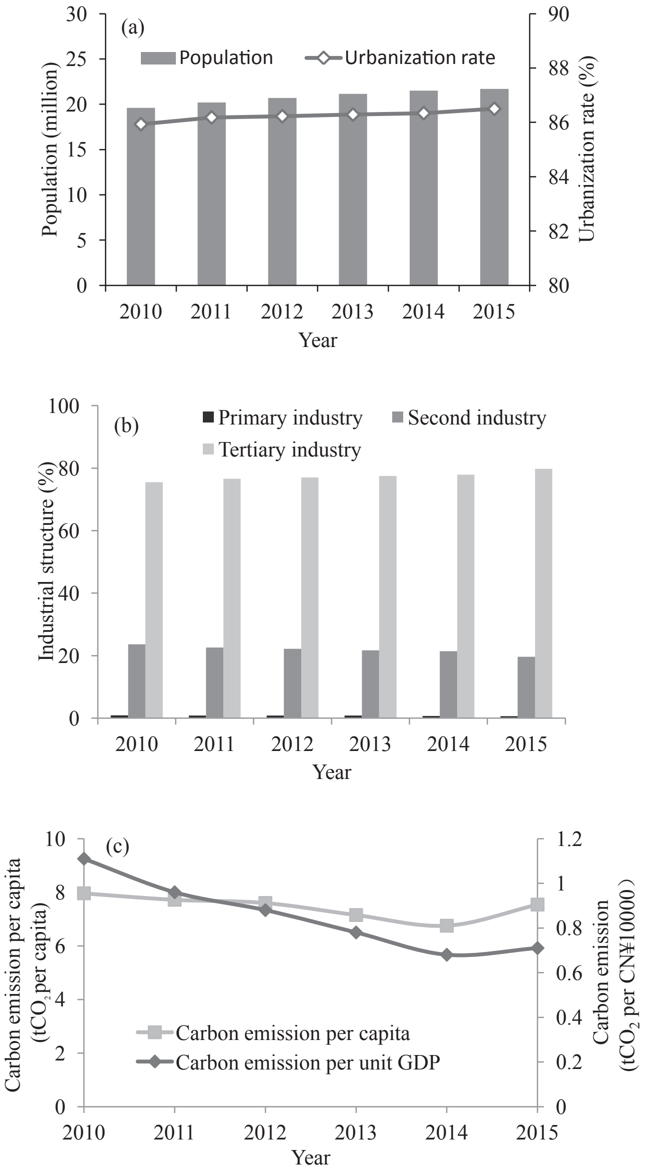

Fig. 4. Pollution and urbanization rate (a), industrial structure (b), and carbon emission per unit GDP and per capita (c) in Beijing in 2010–2015.

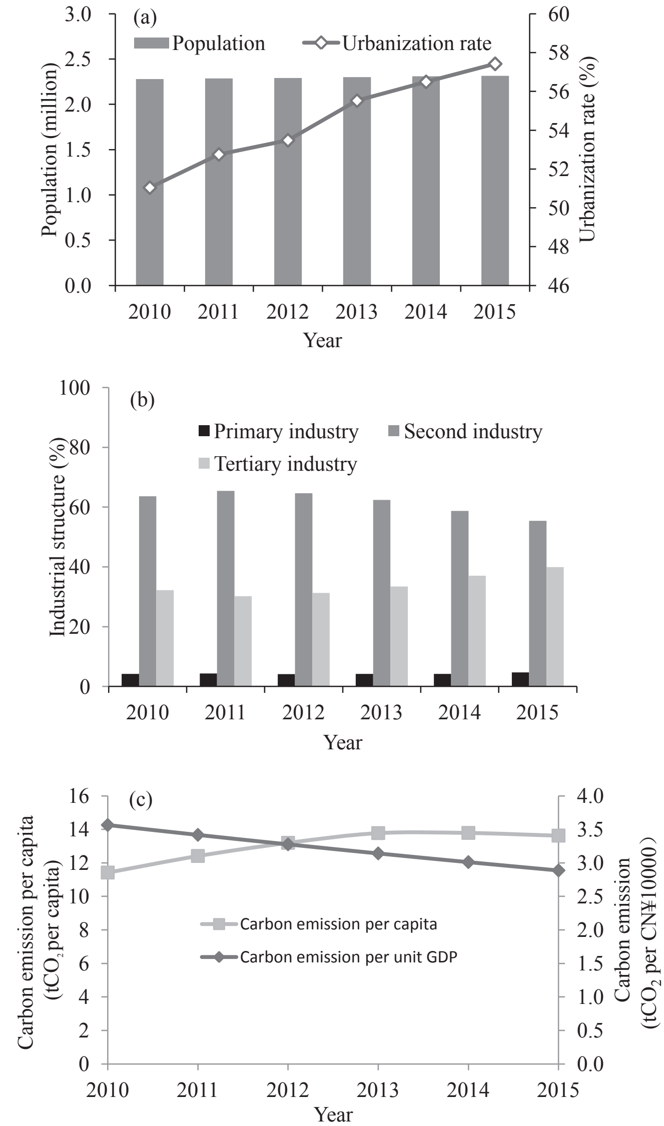

Fig. 5. Population and urbanization rate (a), industrial structure (b), and carbon emission per unit GDP and per capita (c) in Jincheng in 2010–2015.

3.2.3. Case study of a latecomer city: Chizhou

Chizhou is the only one latecomer city in 2015. Located in the inland area of Anhui province along the Yangtze River in Central China, Chizhou is famous for its ecological resources. Sixty percent of its municipal area is covered by forest, and the city was categorized as a latecomer city in 2010 and 2015. It is a medium-sized city with more than 1 million residents and a slow population growth, with an average growth rate of 0.5% during 2010–2015 (Fig. 6a). Its urbanization rate shows a fast growing trend, with an average of 1.3 percentage of increase during 2010–2015. From 2010 to 2015, Chizhou's primary industry was more than 10%, much higher compared with leading and developing cities (Fig. 6b). On the other hand its share of tertiary industry is only 40.9%, 10 percentages lower than the national level in 2015. The social and economic indicators reveal that Chizhou is still in its early stage of urbanization and industrialization.

Chizhou's carbon emission per capita is higher than the national average and keeps growing. Although carbon emission per unit of GDP peaked in 2011 and declined slightly during 2010–2014, it was 2.41 t $CO_2(CN¥10000)^{-1}$ in 2015, more than three times the average of leading cities (Fig. 6c). Therefore the main challenge for GHG control in Chizhou is to raise its economic efficiency to lower the emission per GDP. Therefore finding ways to realize leap-forward development is the developing target for latecomer cities. Unlike leading and developing cities, latecomer cities need to pay more attention to raise their energy efficiency and maximize its latecomer advantages, which is to take a new industrialization pathway and construct urban and rural areas with the low-carbon concept to avoid the phenomenon of “treatment after pollution” in the process of industrial transfer from eastern areas.

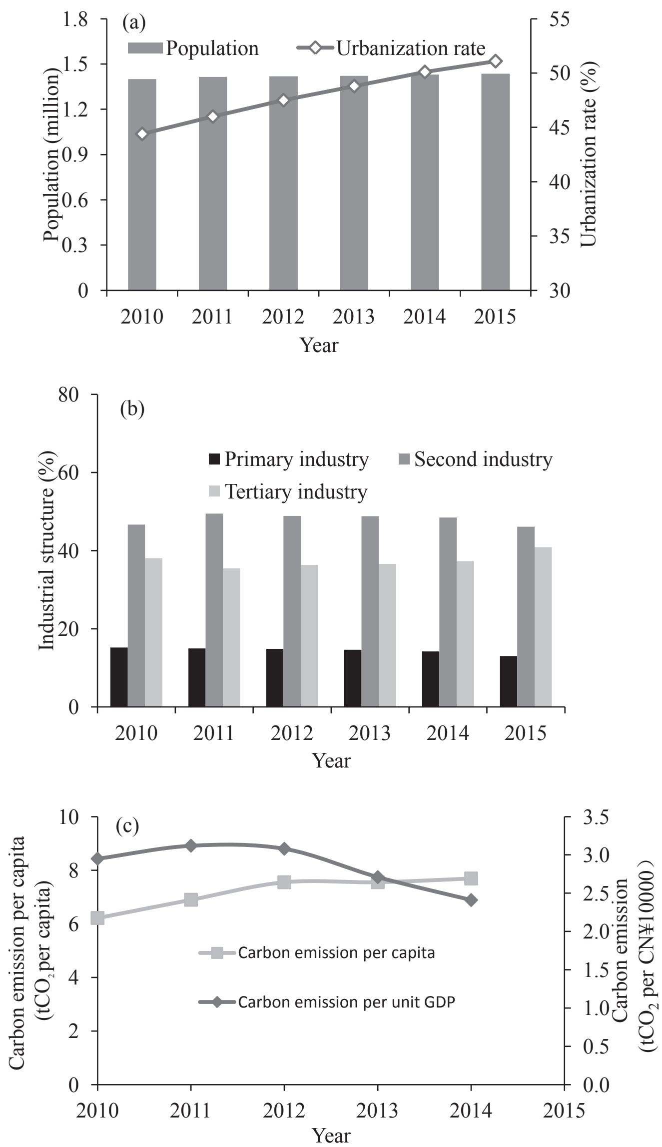

Fig. 6. Population and urbanization rate (a), industrial structure (b), and carbon emission per unit GDP and per capita (c) in Chizhou in 2010–2015 (The data in 2015 is missing due to lack of energy data).

The effort of Chizhou to achieve industrialization and urbanization is constrained by the environment, energy supply, and resources, compared to the former two categories. City scale and the spatial layout play a decisive role in commuting distance between urban residents' daily work and recreation and energy consumption. Also, the urbanization model of this category will directly affect its future transportation emission. The planning of urban forms and industrial layout brought by urbanization and industrialization in the future should be the focus of latecomer cities. They should make an effort to select future industries and try to control its carbon intensity.

3.2.4. Case study of an exploring city: Guangyuan

Guangyuan is in Sichuan province, Southwest China and is a popular travel destination with historical and ecological sites. It situates at the southern foot of Qin Mountain and has abundant resources including forest, water, coal, natural gas, geo thermal etc. It is a medium-sized city with about 2.5 million residents and its current urbanization rate is much lower than the former three cases. It is in a fast urbanization process with annual urbanization rate exceeds 1.5 percentage (Fig. 7a). Guangyuan shows an obvious different industrial structure with the Beijing, Jincheng and Chizhou that its primary industry takes about 20 percentages and its tertiary industry share stays rather stable (Fig. 7b). It has founded 8 agricultural industries with CN¥10 billion in 2015. Guangyuan has a very clean and low-carbon energy system, with hydra power taking account for 98% installed capacity and clean energy takes account for 27% of primary energy. Guangyuan's carbon emission per GDP exhibited a continuous decline during 2010–2015. Although its carbon emission per capita is only 40% of national average, its carbon emission per unit of GDP was almost the same with national average and 70% more than the average of leading cities.

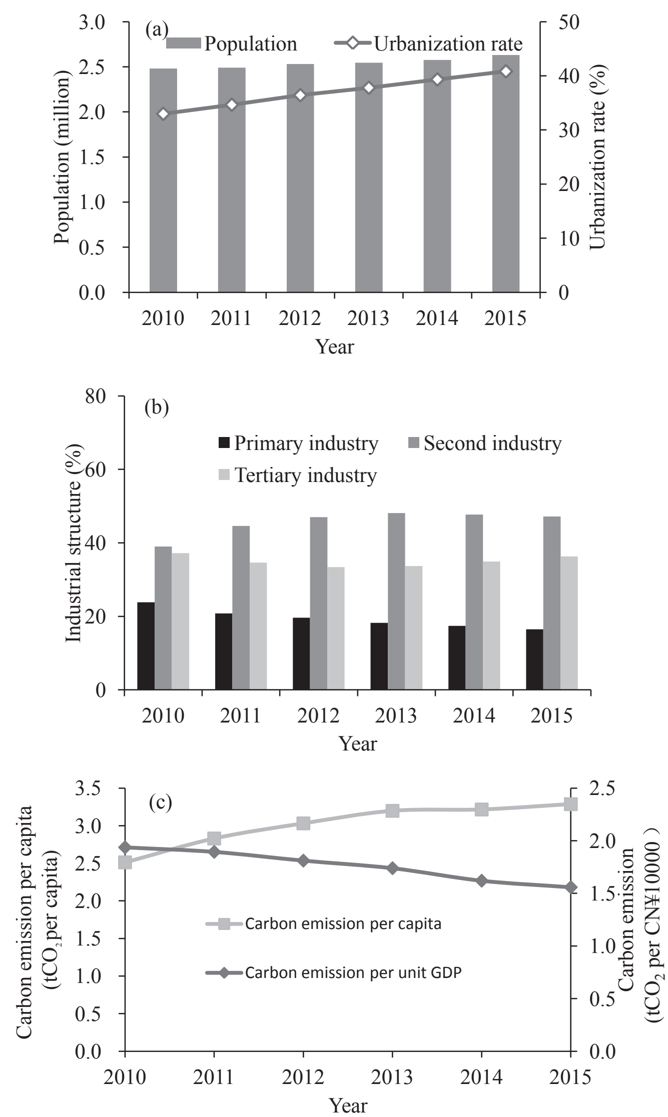

Fig. 7. Population and urbanization rate (a), industrial structure (b), and carbon emission per unit GDP and per capita (c) in Guangyuan in 2010–2015.

Table 3
Comparison of status, challenge and pathway among the four types of cities.

Description	Leading cities	Developing cities	Latecomer cities	Exploring cities
Development stage	Later stage of industrialization, relatively complete urbanization, upper-middle income	Middle stage of industrialization and in the phase of rapid urbanization	Early/middle stage of industrialization and phase of rapid urbanization	Early/middle stage of industrialization and phase of rapid urbanization
Chief target of development	• Continuous improve living standards • Improve environment quality	• Realize economic transition • Protect the environment	• Realize leap-forward development	• Realize leap-forward development • Ecological resources protection
Major challenges for GHG control	Achieve the peak as soon as possible and decrease total GHG emission by controlling the emission growth in living.	• Achieve the peak as the second batch • Control GHG emission in terms of both total amount and intensity	• Control the potential high increase emissions from industry and urban construction	• Control the potential high increase emissions from urban construction
Proposed key measures	• Set a goal for total carbon emission amount control as soon as possible • Improve energy efficiency in building and transport • Promote low-carbon lifestyles and consumption patterns • Increase utilization of clean energy	• Adjust the industrial layout • Slow down the production capacity of new heavy industries, and upgrade the industry system • Carry out urbanization with low-carbon characteristics • Low-carbon lifestyle and consumption pattern	• Focus on energy efficiency • Maximize the advantages of latecomer cities and adopt a new industrialization pathway • Urban and rural construction with low-carbon concept	• Realize a sustainable urban form and industrial structure to avoid the lock-in effect on high carbon mode • Develop related industries with resource endowment • Care for people's livelihood and protect the original life-style and local characteristics
Goal of peaking year	As soon as possible, before 2020	Around 2025	Around 2030	2030−2035

At present, the carbon emission per capita of exploring cities is relatively low, which is related to their current lower economic development and immature industry system. Exploring cities are mostly endowed with good resources, good ecological environment, and abundant ecological resources, such as Daxing'anling (which has a large forest area in the northeast), Guilin (one of the most famous travel destinations in southern China), and Guangyuan (located in southwestern China with a large mountain area and abundant water resources).

The exploring cities are also in the early stage of industrialization and urbanization, resulting in accelerated economic development and a gradual improvement in people's living standard. This situation will obviously lead to a potentially high rise in energy demand and total carbon emissions. However, exploring cities are still constructing their urban layout, and their development model has not yet been solidified. Similar to that of the latecomer cities, the urbanization model of exploring cities will directly affect future carbon emissions in building and transportation, with different future possibilities that may lead to high or relative lower construction amount. In addition, the industrial structure of this category is far from mature and currently dominated by industries with local conditions such as travel, agriculture, etc. Therefore, when exploring the low-carbon development mode, the local resource endowment should be combined with the advantages of natural resources to vigorously develop tourism, ecological agriculture, green food, and other related industries. Such cities should not blindly pursue GDP growth and undertake the transfer of high emission and high-pollution industries from the eastern and central regions.

The exploring cities face minimal pressure with regard to the control of current carbon emissions, but great potential for future growth exists considering the construction of urbanization and improvement of living standards. Therefore, exploring cities should focus on the transformation of urban forms and industrial layout brought by future urbanization and industrialization, as well as the construction of an low-carbon energy system. It should properly slow down economic development, develop people's livelihood, protect the original way of life, maintain local characteristics, and build a new socialist countryside.

3.3. Comparison and low-carbon pathways

From the above indicator analysis and case studies, a comparison and summarize is conducted as shown in Table 3.

4. Summary

In this study, the index system approach and classification analyze is used to analyze and evaluate low-carbon development at city level, in order to propose low-carbon pathways for Chinese cities with distinct conditions under China's peaking target. A seven-indicator system is set up comprising of carbon emission per capita, carbon emission per unit of GDP, GDP per capita, population, urbanization rate, proportion of tertiary industry, and main functional zone. Thirty-six low-carbon pilot cities are selected as research objects. The following conclusions are drawn.

First, there are huge differences in carbon emission and GDP in terms of per capita among cities. It is necessary to categorize cities according to key indicators in order to understand their low-carbon status, trend and challenge with various characteristics. Four categories are defined in this paper, which are leading cities, developing cities, latecomer cities and exploring cities.

Second, the development stage, chief target of development, major challenges for GHG control are analyzed by indicator analysis and case study for the four categories, and key measures for low-carbon development are proposed accordingly.

Third, on the basis of the current situation and the objectives of national emissions and considering the differences of development stages and demand between various types of cities, a peaking roadmap for the medium- and long-term (by 2030) in China is proposed:

- Leading cities: carbon emission per capita will basically stop increasing or slow down from now on. They aim to achieve peak emissions by around 2020. After a period of plateau, the indicator of emission per capita will fall. On the basis of the absolute quantity of carbon emission, construction, and transportation emission-related indicators, leading cities can be evaluated to measure their low-carbon development status.
- Developing cities: efforts should be taken to slow down the emission growth and actively promote the transition of the economy and of energy systems to achieve a relatively high emission peak by around 2025.
- Latecomer cities: it is aimed to achieve the peak emission by around 2030, attempt to realize a slowly rising in carbon emission by leap-forward development.
- Exploring cities: it is aimed to achieve the peak emission in 2030–2035, attempt to achieve a relative low emission level at the peak value.

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