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RESEARCH ARTICLE

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Case-based reasoning for selection of the best practices in low-carbon city development

Abstract Cities emit extensive carbon emissions, which are considered a major contributor to the severe issue of climate change. Various low-carbon development programs have been initiated at the city level worldwide to address this problem. These practices are invaluable in promoting the development of low-carbon cities. Therefore, an effective approach should be developed to help decision makers select the best practices from previous experience on the basis of the impact features of carbon emission and city context features. This study introduces a case-based reasoning methodology for a specific city to select the best practices as references for low-carbon city development. The proposed methodology consists of three main components, namely, case representation, case retrieval, and case adaption and retention. For city representation, this study selects city context features and the impact features of carbon emission to characterize and represent a city. The proposed methodology is demonstrated by applying it to the selection of the best practices for low-carbon development of Chengdu City in Sichuan Province, China.

Keywords low-carbon city, carbon emission, best practices, case-based reasoning

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1 Introduction

Carbon emissions, which are major contributors to climate change, have increased due to industrialization and urbanization (Jebaraj and Iniyan, 2006; Brännlund and Lundgren, 2007; Liu et al., 2013; Lo, 2014; Wang et al., 2014; Yu, 2014). The consequences of climate change occur in multiple dimensions across economic, social, and ecologic aspects (Chen et al., 2019). As centers for population, industry, transport, and infrastructure, cities exert a profound impact on global carbon emissions (Khanna et al., 2014; Mi et al., 2019). Although cities occupy only 2% of the Earth's surface, they are responsible for 67% of the global energy consumption and over 70% of the total global greenhouse gas (GHG) emission (Williams, 2007; Chan et al., 2013; Seto et al., 2014). Thus, cities play a key role in contributing to the reduction of GHG emissions (Yang et al., 2018).

An effective approach for promoting low-carbon cities is to learn from previous similar experience. Multiple types of experience have been generated from low-carbon city implementation (Wang et al., 2019). Many studies have reported that the low-carbon city pilot program is effective in promoting carbon emission reduction (Khanna et al., 2014). According to the report by the National Development and Reform Commission of China (NDRC) (Kedia, 2016), the carbon intensity in 10 pilot provinces and cities (i.e., provinces of Shanxi and Liaoning and cities of Tianjin, Baoding, Hangzhou, Chongqing, Nanchang, Guiyang, Xiamen, and Shenzhen) decreased by nearly 9.2% in 2012. Cities in the low-carbon city pilot program have accumulated extensive experience in carbon emission reduction, such as improving energy efficiency, applying renewable energy, adjusting the sector structure, and increasing carbon sequestration capacity.

Apart from China, many other countries and organizations worldwide have exerted much effort in promoting the development of low-carbon cities. For example, the 40 cities in the C40 Cities Climate Leadership Group (C40) have defined various specific low-carbon strategies and actions to promote carbon emission reduction (Tan et al., 2017). Bangkok in Thailand has presented policies and interventions related to energy saving for reducing carbon emissions (Phdungsilp, 2010). Many states and cities in the United States have established low-carbon goals and plans (Gomi et al., 2010). The Prime Minister's Office of Japan only accepted cities for "Environmental Model Cities" in April 2008 and has set long-term low-carbon targets (Gomi et al., 2010). The governments of London, California, and Berlin have proposed several quantitative assessment tools for carbon emissions and measures for reducing them (Berlin Agenda Forum, 2004; California Environmental Protection Agency, 2006; Greater London Authority, 2007). Several cities, including Tokyo, London, and New York, have initiated a series of planning programs to promote the development of low-carbon cities (Su et al., 2013).

Experience is crucial, and the lessons learned from it provide important references on promoting low-carbon city development in specific cities (Li et al., 2018). Given that investigation of all previous experience is impossible with limited time and budget, several of the best practices for a specific city may have been missed out in previous research. This scenario reveals the importance of identifying the most relevant and effective experience for a specific city planning for low-carbon development. Currently, systemic approaches that aid in the search for low-carbon city development experience are lacking. The use of experience in the past focused on the nature of the problem, and minimal attention has been provided to the context features of a specific city. The effectiveness of experience reuse is limited when city features are disregarded. The application of previous experience to the implementation of low-carbon cities depends on the local socioeconomic, environmental, and political characteristics of each city. Application of inappropriate experience hinders the development of low-carbon cities and results in losses in time and capital. Thus, a holistic approach that integrates the socioeconomic, environmental, and geographical conditions of a city should be developed to aid low-carbon city developers in efficiently identifying the best practices for specific cases.

Various studies have been conducted on low-carbon city development practices. For example, by combining the conditions of China with the advanced practices of foreign countries, Yang and Li (2013) reported some experience in building a low-carbon city from the dimensions of energy use, transportation, housing, employment, service facilities, green infrastructure, water resource use, and waste disposal. Li et al. (2012) presented the main approaches in developing low-carbon towns in China. The proposed approaches included economic, social, layout, technological, and reuse approaches. Kedia (2016) reviewed emerging approaches and efforts on low-carbon city development in China and India in relation to financing, science, technology, innovation policies, and subnational actions for other countries to learn from such experience. On the basis of discussions about China's efforts and policies in promoting transition to a low-carbon economy, Zhang (2010) provided several recommendations for issues related to energy conservation, pollution control, wind power, nuclear power, clean coal technologies, and overseas oil and gas supplies; he also presented a roadmap for achieving China's climate commitments by 2050. Liu and Qin (2016) reviewed low-carbon city initiatives in China from the policy paradigm.

Many studies have focused on the low-carbon city development experience at the sector level. Considering that building construction is important in climate change mitigation, Lin and Liu (2015) investigated the relationship between CO_2 mitigation potential and energy performance in the building construction industry, which is a prerequisite of low-carbon development strategies in the building sector. Pathak and Shukla (2016) indicated that cities in developing countries can leverage carbon finance to develop sustainable, low-carbon transportation plans that prevent adverse infrastructure and behavioral lock-ins and prompt low-carbon development. Jiang and Tovey (2009) established a comprehensive approach to achieve low carbon sustainability in large commercial buildings in China by incorporating energy and carbon reduction strategies.

Another group of literature has focused on case studies about the practices of individual cities in promoting low-carbon development. For example, Lind and Espegren (2017) introduced a technology-rich optimization model to analyze the transformation of Oslo into a low-carbon city through various energy and climate measures. Fenton (2017) provided several carbon reduction measures for Odense City in Denmark by evaluating the relationship between low-carbon city development and sustainable mobility. Bi et al. (2011), Lehmann (2012), Liu et al. (2012) , and Pathak and Shukla (2016) investigated low carbon practices and lessons obtained from Nanjing, Shanghai, and Chongqing in China and Ahmedabad in India, respectively.

These studies summarized previous practices and experience in low-carbon city development that are useful for promoting low-carbon city development. However, no tools or practices are available to aid low-carbon city developers in efficiently identifying the best practices in low-carbon development for planning and implementation. This study introduces a case-based reasoning (CBR) approach for determining the best practices in low-carbon city development by considering the nature of carbon emission problems and city context features. Several studies have applied the CBR method in sustainable city development. For example, Shen et al. (2013) and Shen et al. (2017a; 2017b) presented an experience mining system based on the principle of CBR to obtain useful experience from existing best sustainable urbanization practices.

The remainder of this paper is organized as follows. Section 2 introduces the research methodology. Section 3 explains the CBR methodology in the context of low-carbon development in detail. Section 4 demonstrates the application of CBR by using the case of Chengdu in China as an example. Section 5 discusses the main results, and Section 6 presents the research conclusions.

2 Methodology

2.1 Case-based reasoning

The development of CBR can be divided into three stages. In the first stage, CBR was implemented with schema-oriented memory models (Bartlett, 1932). Many prototype systems of CBR, such as CYRUS (Kolodner, 1983), CHEF, and MEDIATOR (Riesbeck and Schank, 1989; Kolodner, 1993), were built during the first stage. In the second stage, many CBR workshops were organized, and there were three CBR workshops organized by the U.S. Defense Advanced Research Projects Agency in 1988, 1989, and 1991 and the first German workshop on CBR in 1992. A book defining CBR was published by Kolodner (1993) in 1993, and Aamodt and Plaza (1994) introduced the CBR cycle in 1994. At present, which is the third stage, web, Internet, and data mining algorithms and collaborative and social system integrations frequently appear in CBR publications.

CBR is a scientific approach based on the observation that similar cases have similar solutions. CBR uses a human-inspired philosophy to solve a problem, which indicates that a new problem can be solved by referring to the solutions of previous similar problems (Shen et al., 2017a; 2017b). In the application of CBR methodology, a base of previous cases should be established initially. CBR users can retrieve past similar cases from the case base when a new problem arises, and the solutions adopted in the retrieved cases can be used as references to solve new problems. Users can directly apply these solutions when they match the current problem. Otherwise, CBR users should revise the retrieved previous solutions. The new problem and its associated solution should be added to the case base after users have successfully solved their problems by applying CBR. CBR is commonly acknowledged to be more effective in weak-theory domains compared with mathematical models because the recording and presenting of knowledge in weak theory are case-specific, and many previous cases exist and can be reused for solving new problems (Yeh and Shi, 2001). On the contrary, mathematical models are normally required to make explicit associations and generalized relationships between problems and conclusions. This condition makes CBR a suitable approach for this study, in which low-carbon practices are implemented to reduce carbon emissions and many low-carbon city cases are available. The CBR method has been widely applied in various domains, such as medical diagnosis and prescriptions (El-Sappagh et al., 2015; Saraiva et al., 2016), product design (Yang and Chen, 2011; Shen et al., 2017a; 2017b), manufacturing (Liu and Ke, 2007; Wu et al., 2008), decision making (Zhang and Dai, 2018), and construction management (Chou, 2009; Koo et al., 2010).

As shown in Fig. 1, the CBR method has five components, namely, represent, retrieve, reuse, revise, and retain (Aamodt and Plaza, 1994).

(1) Represent: case presentation is applied to organize cases, which can be regarded as contextualized experience in the case base, so as to enable the computer to organize, store, and process past cases.

(2) Retrieve: case retrieval is the process of determining the most relevant and similar cases within the case base for a new case.

(3) Reuse: case reuse involves adopting the solution stored in the retrieved cases as a reference to solve the target problem.

(4) Revise: the retrieved solution is evaluated to determine whether it suits the new case and solves the target problem or not; otherwise, revision is required to obtain a verified solution.

(5) Retain: after the target problem is successfully addressed by adopting the confirmed solution, the target problem and its associated solution are stored in the case base.

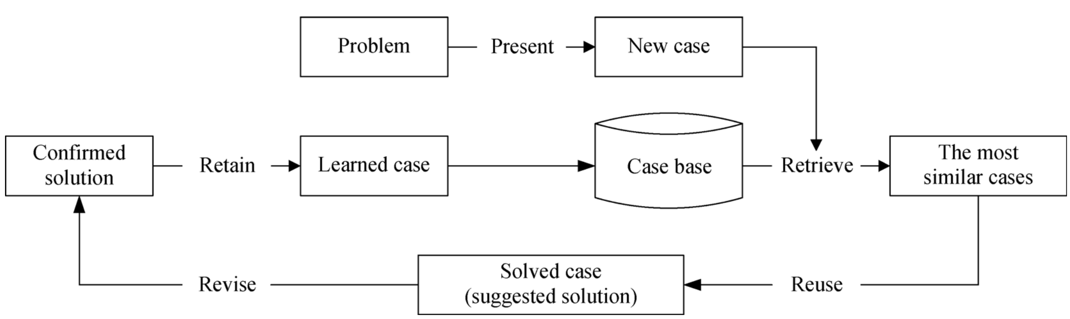

Fig. 1 Cycle of case-based reasoning

2.2 CBR for the selection of the best practices in low-carbon city development

This study introduces a methodology for the selection of the best practices based on the principle of CBR to support the decision making in low-carbon city development. The methodology involves three components, as shown in Fig. 2.

2.2.1 Case presentation

The first step in the proposed methodology is to present a city in a structured format. A widely applied means of case presentation is selecting a set of principal features or attributes and their corresponding values. Current practices of low-carbon city modeling focus on the problem domain and ignore the contextual features of a specific city. City context features have a profound influence on the selection of the best practices for a specific city when promoting low-carbon city development.

To fill this gap, this study uses two categories of features for case presentation, namely, city context and key impact features of carbon emission.

(1) Selection of city context features

As mentioned in the Introduction, existing studies that proposed measures for promoting the development of low-carbon cities did not consider city context features. City context features should be considered because they exert a significant impact on the carbon emission of cities and which practices should be adopted, a claim that was echoed by Zhang (2016) and Zhou et al. (2015). The significance of contextual information is also widely recognized by researchers in various disciplines, such as e-commerce personalization (Oku et al., 2006), information retrieval (Jones, 2005), ubiquitous and mobile computing (Schilit and Theimer, 1994), data mining (Berry and Linoff, 1997), databases (Stefanidis et al, 2008), and marketing and management (Lilien et al., 1995). The concept of context is multifaceted and idiosyncratic in each discipline. According to Dourish (2004), context can be defined as a set of attributes that influence human behavior.

Through a literature review, this study selects four typical city context features, namely, landform, climate zone, city scale, and development stage. Each feature is measured by indicator values. For instance, the development stage is described by the indicator urbanization rate. These city context features and their measuring indicators are summarized in Table 1.

1) Landform

Landform can influence the selection of the best low-carbon city practices from many dimensionalities. On one hand, landform has an impact on the building layout of a city. The energy consumption patterns of buildings in cities with different building layouts have their own characteristics (Xiao et al., 2014). On the other hand, the traffic systems in cities within different landforms differ in terms of energy consumption. These differences caused by landform result in different performance in carbon

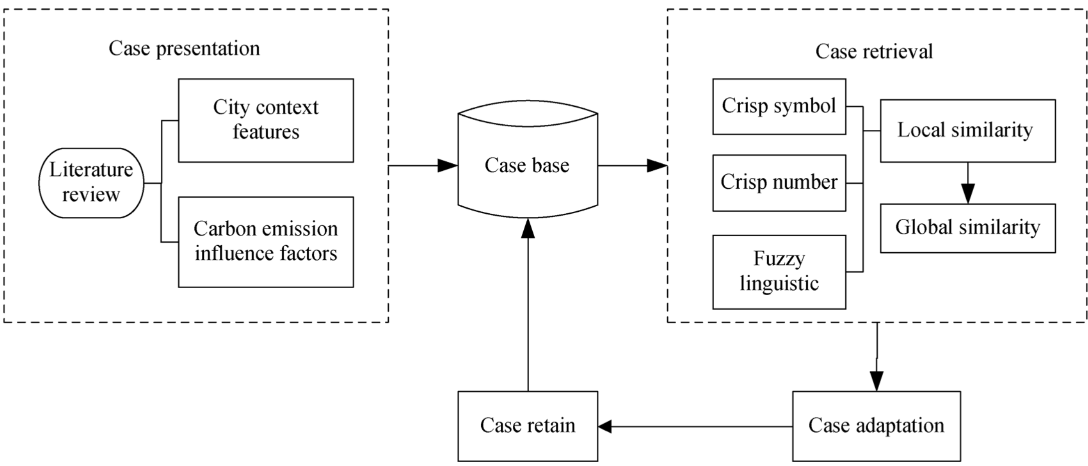

Fig. 2 Framework of CBR in the selection of the best practices

Table 1 City context features and their indicators

City context feature	Indicator value
Landform	Hills, mountains, plains, and plateaus
Climate zone	Severe cold, cold, mild, hot summer and cold winter, and hot summer and warm winter
City scale	Small city, medium-size city, large city, super city, and mega city
Development stage	Urbanization rate

emission.

2) Climate zone

Climate type has an impact on the carbon emission of a city in many aspects. According to the *Code for Design of Civil Buildings* (Ministry of Construction of the People's Republic of China, 2005), five climate zones, namely, severe cold, cold, mild, hot summer and cold winter, and hot summer and warm winter, exist in China. Cities in different climate zones have different forms and intensities of energy consumption. Thus, strategies for carbon emission reduction should be formulated by considering the characteristics of different climate zones in which individual cities are located. For example, 16 out of 34 provinces in China are located in the climate zone of hot summer and cold winter, and most of the annual energy is consumed for air conditioning. Thus, the governments in these cities in the hot summer and cold winter climate zone should establish measures to reduce the energy consumption and carbon emission of cooling and heating systems. On this basis, this study selects climate zone as a city context feature, and the corresponding values of this indicator include severe cold, cold, mild, hot summer and cold winter, and hot summer and warm winter.

3) City scale

Cities with different size scales have different carbon emission patterns, and effective carbon emission reduction measures should consider the city scale feature. Several researchers have emphasized this feature. For example, Xie et al. (2017) indicated that the transportation infrastructure in large-scale cities could increase carbon emissions, and the transportation infrastructure in medium-sized cities significantly increases carbon intensity but not carbon emissions; this pattern is not significant in small cities. Thus, the practices of reducing carbon emission in the three city groups are different. Xie et al. (2017) suggested that large-scale cities should take measures to improve the efficiency of transportation infrastructure. Medium-scale cities should strengthen the construction of low-carbon transportation systems. For small-scale cities, transportation infrastructure has no significant impact on carbon emissions and carbon intensity. Thus, small cities should develop many advanced transportation infrastructures. In summary, city scale should be considered by low-carbon city developers when making strategic decisions. On this basis, this study includes the city scale feature in the list of city context features. In accordance with the principle established by the Economic Development Council of Small and Medium-sized Cities in China Society of Urban Economy (2010), this study classifies cities into five categories, as follows:

- Small city: the population is less than 5×10^5;
- Medium-size city: the population is between 5×10^5 and 10^6;
- Large city: the population is between 10^6 and 3×10^6;
- Super city: the population is between 3×10^6 and 10^7;
- Mega-city: the population is more than 10^7.

4) Development stage

The development stage of a particular city can be characterized by urbanization level to reflect the population shift from rural to urban areas (United Nations, 2010). Studies have revealed that cities in different development stages with different urbanization levels should take different steps when promoting the development of low-carbon cities. Shi and Li (2018) divided Chinese cities into three development stages according to the urbanization level and suggested that the improvement in the efficiency of energy consumption of the high-end manufacturing industry in the highly developed stage is a top priority in reducing carbon emissions. Liu et al. (2018) suggested that policy formulation for low-carbon city development should consider the development stage of cities. For example, mega cities with a high urbanization level cannot expand their urban areas. Thus, city management optimization and information technology utilization are the key factors to reduce traffic congestion, which is a main source of carbon emission. For emerging cities with low urbanization rates, defining the city role and spatial layout scientifically and developing "compact" space are the key factors in promoting low-carbon development in the long run. These measures are effective for reducing the daily commuting distance within the city and eventually decreasing the carbon emission of a city's transportation system. Thus, this study selects development stage as a city context feature.

In accordance with the Northam curve (Northam, 1979), the development stage of a city can be classified into three stages as follows:

- Early stage: the urbanization rate is below 30%;
- Middle stage: the urbanization rate is between 30% and 70%;
- Mature stage: the urbanization rate is above 70%.

(2) Selection of key impact features of carbon emission

Impact features of carbon emission refer to the features of a city that have a direct or indirect influence on CO_2 emission with a significant degree of impact. All of the impact factors of carbon emission in cities cannot be used as problem domain features in this study. Thus, this study identifies the key impact features of carbon emission. Previous literature on carbon emission factors are reviewed, and 19 key impact features of carbon emission in cities are selected from the seven perspectives of energy, transportation, building, waste, land use, water, and economy, as shown in Table 2.

1) Energy

Energy production and consumption are the largest sources of carbon emission and account for two-thirds of global emissions (International Energy Agency or IEA, 2013). Driven by industrialization, industries consume the largest percentage of energy and account for most of the total carbon emission. In China, 90% of energy

Table 2 Key impact features of carbon emission in cities

Sector	Key impact features of carbon emission
Energy	• Industrial energy consumption per capita/(tce · person^{-1}); • Household use of electricity per capita/(kW · h · person^{-1}); • Proportion of renewable and clean energy/%; • Amount of central heating supply per capita/(GJ · person^{-1})
Transportation	• Road area per capita/(10^4 m^2); • Public buses per capita/(vehicle · 10^{-4} person^{-1}); • Volume of freight/(10^4 t); • Private cars per capita/(vehicle · 10^{-4} · person^{-1})
Building	• Area of green buildings/(10^4 m^2)
Waste	• Ratio of industrial solid waste comprehensively utilized/%; • Domestic garbage treatment rate/%
Land use	• Average per-capita public green land/ (hectares · 10^{-4} · person^{-1}); • Area of built districts per capita/(km^2 · person^{-1})
Water	• Volume of industrial waste water discharged/(10^4 t); • Annual quantity of wastewater discharged/(10^4 m^3); • Quantity of wastewater treated/(10^4 m^3); • Amount of water supply/(10^4 t)
Economy	• GDP per capita/(CNY · person^{-1}); • Proportion of tertiary industry to GDP/%

consumption takes place in the industrial sector (Lin and Liu, 2010), and 42%–44% of the total annual carbon emissions from 1992 to 2012 were emitted from the manufacturing industry (Tian et al., 2018), Thus, this study selects the feature of industrial energy consumption per capita. According to a report of IEA, the carbon emissions from electricity and heat generation sectors are substantial and accounted for 38% of the total carbon emission in 2010. This condition is due to the fact that coal is still the dominant fuel for electricity and heat generation at present. Moreover, the supply of central heating in the northern region of China is higher than that in the southern region because the winter in northern China is extremely cold and long, and central heating systems are provided to northern cities for 120 to 180 days each year based on the local temperature. At present, coal is the main energy source of central heating, and substantial carbon emissions are produced in these northern cities. The amount of heating supply should be considered a city attribute. Thus, this study selects the features "household use of electricity per capita" and "amount of central heating supply per capita." In addition, the proportion of renewable or clean energy in the energy resource structure is another key factor in determining the carbon emission of this sector. Hence, the feature "proportion of renewable and clean energy" is also selected.

2) Transportation

Carbon emissions produced by transportation systems are mainly from the use of private cars, public transport, and freight transport. Among the three, private cars have always been the largest emitter in the urban transport system. In Shanghai, private cars consumed approximately 50% of the total energy consumed by all means of transportation in 2005. Therefore, the number of private cars is an important feature of transportation systems. The development of public transport can effectively reduce carbon emissions and air pollution, and the scale of public transport in a city is an important factor that influences carbon emission. Thus, this study selects two features of "public buses per capita" and "road area per capita" to indicate the scale of public transport. In addition, a transportation system is responsible for ferrying goods from one place within or outside a city to another place to enable cities to sustain robust economic growth. Freight transport is a significant source of carbon emissions. Specifically, in developing countries, many material resources are transported for the development of the economy and society, leading to frequent freight activities and considerable carbon emission in cities. The feature "volume of freight" is selected in this study based on these facts.

3) Building

The building sector is also a main carbon emitter (Chen et al., 2019a). Previous studies have suggested that building operations consume approximately one-third of the world's total energy, and the energy demand in the building sector is estimated to grow by nearly 50% by 2050 if it is not controlled, leading to a large amount of carbon emission (International Energy Agency, 2013). In China, residential buildings consumed approximately 10.3% of the national carbon emission in 2012 (Fan et al., 2015). The practice of green building has been widely accepted as an effective means to mitigate the problem of carbon emission from buildings. This practice was supported by the study of Wu et al. (2017), who found that carbon emissions from green buildings are lower than that from non-green buildings, that is, 10% less for residential and 32% less for commercial buildings. The promotion of green buildings has a positive impact on carbon emission. Thus, this study selects the feature "area of green buildings."

4) Waste

Municipal waste can generate carbon emissions during waste management and disposal. GHG emissions from waste accounted for approximately 3% of the worldwide GHG emission in 2010 (Blanco et al., 2014). In developing countries, emissions from waste can account for a large percentage and reach 15% of the total national emissions (Friedrich and Trois, 2011). The amount of waste remarkably increases with the rapid development of urbanization and the growth of GDP and population in China. China generated approximately 170 million tons of solid waste in 2012, which increased by 11.5% when compared with the amount in 2006; the average annual growth rate was 2.4% between 2006 and 2012. An increase in the amount of waste naturally leads to an increase in waste collection and transportation. In addition, natural degradation of waste produces considerable carbon emissions. The waste sector has become a primary source of GHG emissions due to the continuous rapid increase in the amount of waste. Thus, this study selects “ratio of industrial solid waste comprehensively utilized” and “domestic garbage treatment rate” to represent the features of the waste sector.

5) Land use

Many land types in cities have different levels of influence on carbon emission. For example, the amount of carbon emissions increases when farmland or forestland is converted into urban construction land. Farmland and forestland are carbon sinks that could sequester and store carbon, and changes in land function and a decrease in the area of farmland and forestland damage the capability of a city to absorb carbon emissions. Thus, this study selects “the percent of area of built districts per capita” and “area of public green land per capita” as indicators to characterize a city from the perspective of land use. A report from the Intergovernmental Panel on Climate Change (IPCC) (2014) has shown that land use pattern is a major driver of carbon emissions.

6) Water

An increasing number of people live in urban areas due to rapid urbanization, resulting in an increase in urban water use (Escriva-Bou et al., 2018). Water needs to be supplied, conveyed, and treated in every corner of a city where production and living activities are ongoing. In addition, wastewater should be treated, transported, and disposed. All of these activities require energy and discharge considerable carbon emissions (Reffold et al., 2008). According to *China Urban Construction Statistical Yearbook 2012*, the total wastewater from cities reached 41.676 billion cm^3 at the end of 2012 (Ministry of Housing and Urban-Rural Development of the People’s Republic of China, 2013). A significant amount of GHGs is generated during the transport, treatment, and disposal of such vast quantities of wastewater. Thus, this study selects “volume of industrial waste water discharged,” “quantity of wastewater discharged,” “quantity of wastewater treated,” and “the amount of water supply” to characterize the water sector of a city.

7) Economy

The economic performance and economic structure of a city are important factors that influence carbon emissions. A substantial amount of energy is required for a city to maintain constant economic growth and normal functioning and meet the needs of citizens. This large amount of energy consumption causes an increase in carbon emission. The situation is much worse in developing countries. Many studies have revealed that economic development is a main influencing factor of carbon emission. For example, Zhang et al. (2011) found that increasing GDP causes the largest increase in carbon emissions in China. Wang et al. (2012), Yao et al. (2015), Wang et al. (2017) and Zoundi (2017) suggested that the real GDP per capita is the main influencing factor of carbon emission in Beijing City, 25 African countries, Xinjiang Province, and G20 countries. Many studies have also indicated that the proportion of GDP from the tertiary industry plays a key role in carbon emission (Wang et al., 2012; Fu et al., 2015; Wang et al., 2017). In this study, the features of “GDP per capita” and “proportion of GDP from the tertiary industry” are selected.

2.2.2 Case retrieval

The similarity between cities is critical to CBR for the recommendation of low-carbon practices. The aim of case retrieval is to find the cases in the case library that are the most similar to the target case. To achieve this aim effectively, this study uses the local-global method, which is widely used in measuring similarity, to determine the similarity between cities (De Mántaras et al., 2005).

The application of the local-global method involves two steps. The first one is to calculate the local similarity between different cities for each feature. The second step is to calculate the global similarity between different cities by using the weights associated with the local similarity of each feature.

(1) Local similarity measure

Urban features are measured by three types of value formats, namely, crisp symbol, crisp number, and fuzzy linguistic value, as shown in Table 3. Crisp symbol can be used to express features with definite meanings. For example, the “landform” feature can be expressed by “hills,” “plains,” “mountains,” and “plateaus.” Crisp number can describe features with a certain value. For example, the value of “GDP per capita” is “2000 USD.” Fuzzy linguistic variable is a natural language expression or word that imprecisely describes an attribute (Pal and Shiu, 2004; Shen et al., 2017a; 2017b). For example, urbanization development stages can be described by fuzzy linguistic terms “early stage,” “medium stage,” and “mature stage.” Different methods should be used to calculate the local similarity of features with different types of value formats.

1) With regard to the features expressed by a crisp symbol, the local similarity between the target city and case city can be calculated by judging whether or not the feature values are equal, which can be expressed by using Eq. (1).

$$sim_1(Q_{ij},Q_{0j}) = \begin{cases} 1 & \text{if } Q_{ij} = Q_{0j}, \\ 1 & \text{if } Q_{ij} \neq Q_{0j}, \end{cases} \tag{1}$$

where $sim_1(Q_{ij},Q_{0j})$ denotes the similarity between case city C_i and target city C_0 in terms of feature F_j with a crisp symbol. Q_{ij} and Q_{0j} denote the values of F_j in case city C_i and target city C_0, respectively.

2) With regard to the features expressed by a crisp number, the local similarity between the target city and

Table 3 Format of each feature

Features	Format of feature value
• Landform	Crisp symbol
• Climate zone	Crisp symbol
• Industrial energy consumption per capita	Crisp number
• Household use of electricity per capita	Crisp number
• Proportion of renewable and clean energy	Crisp number
• Amount of central heating supply per capita	Crisp number
• Road area per capita	Crisp number
• Public buses per capita	Crisp number
• Volume of freight	Crisp number
• Private cars per capita	Crisp number
• Area of green buildings	Crisp number
• Ratio of industrial solid waste comprehensively utilized	Crisp number
• Domestic garbage treatment rate	Crisp number
• Average per-capita public green land	Crisp number
• Area of built districts per capita	Crisp number
• Volume of industrial waste water discharged	Crisp number
• Annual quantity of wastewater discharged	Crisp number
• Quantity of wastewater treated	Crisp number
• Amount of water supply	Crisp number
• GDP per capita	Crisp number
• Proportion of tertiary industry to GDP	Crisp number
• City scale	Fuzzy linguistic
• Development stage	Fuzzy linguistic

case city can be measured by calculating the distance between the values of the two crisp numbers. The similarity can be obtained by applying Eq. (2).

$$sim_2(Q_{ij},Q_{0j}) = 1-\frac{|Q_{ij}-Q_{0j}|}{(\beta-\alpha)},\ Q_{ij},Q_{0j} \in [\alpha,\beta], \tag{2}$$

where $sim_2(Q_{ij},Q_{0j})$ presents the similarity between case city C_i and target city C_0 in terms of feature F_j with a crisp number. α and β denote the minimum and maximum original values of feature j, respectively, across all case cities and the target city.

3) The similarity between the case city and target city in terms of feature j in the format of a fuzzy linguistic value can be calculated using Eq. (3) on the basis of fuzzy distance calculation proposed by Pal and Shiu (2004).

$$sim_3(Q_{ij},Q_{0j}) = 1-\frac{\int_\alpha^\beta\int_\alpha^\beta u(x)u(y)|x-y|\mathrm{d}x\mathrm{d}y}{(\beta-\alpha)\int_\alpha^\beta u(x)\mathrm{d}x\int_\alpha^\beta u(y)\mathrm{d}y}, \tag{3}$$

where $sim_3(Q_{ij},Q_{0j})$ denotes the similarity between case city C_i and target city C_0 in terms of feature F_j with a fuzzy linguistic value. $u(x)$ and $u(y)$ are the member functions of fuzzy linguistic variables Q_{ij} and Q_{0j}.

In this study, one fuzzy linguistic variable, "development level," is used. The determination of the membership function is subjective in nature. This study uses a trapezoidal membership function to describe the city features of "development level" in accordance with Shen et al. (2017a; 2017b). The membership functions of "development level" are shown in Eqs. (4)–(6).

$$u_{\text{early}}(x) = \begin{cases} 1 & x\leqslant 0.2, \\ \dfrac{0.4-x}{0.4-0.2} & 0.2 < x\leqslant 0.4, \\ 0 & 0.4 < x, \end{cases} \tag{4}$$

$$u_{\text{middle}}(x) = \begin{cases} 0 & x\leqslant 0.2, \\ \dfrac{x-0.2}{0.4-0.2} & 0.2 < x\leqslant 0.4, \\ 1 & 0.4 < x\leqslant 0.6, \\ \dfrac{0.8-x}{0.8-0.6} & 0.6 < x\leqslant 0.8, \\ 0 & 0.8 < x, \end{cases} \tag{5}$$

$$u_{\text{mature}}(x) = \begin{cases} 0 & x\leqslant 0.6, \\ \dfrac{x-0.6}{0.8-0.6} & 0.6 < x\leqslant 0.8, \\ 1 & 0.8 < x. \end{cases} \tag{6}$$

(2) Global similarity measure

The global similarity between the case city and target city can be calculated by integrating the local similarity of all features and applying Eq. (7).

$$sim(C_i,C_0) = \sum\nolimits_{j=1}^{29} sim(Q_{ij},Q_{0j}), \tag{7}$$

where $sim(C_i,C_0)$ denotes the global similarity between case city C_i and target city C_0 and $sim(Q_{ij},Q_{0j})$ denotes the similarity between case city C_i and target city C_0 in terms of the ith feature, which can be calculated using Eqs. (1)–(3).

2.2.3 Case adaptation and retention

Case adaptation fixes old solutions to meet the demands of a new situation (Kolodner, 2014). Although old solutions can be used as a reference in solving new problems, new cases rarely match old ones exactly. Thus, the retrieved old solutions need to be adjusted. After case retrieval, users of the proposed methodology can obtain the most similar cities and their associated low-carbon city practices. These practices have a high possibility of being selected to promote the low-carbon development of a target city. However, the target city is different from any retrieved cities, although they share a high similarity level. Thus, some adjustments should be made on the retrieved low-carbon practices to make them match the target city well. The governments of target cities should analyze these retrieved practices and determine which practices are required. The last step in the CBR cycle is case retention, which integrates new cases into the case base for future use. The process of case adaptation and retention enables the CBR methodology to possess a capability for continuous performance improvement.

3 Application of the proposed methodology

To demonstrate the proposed methodology, we select Chengdu City of Sichuan Province as the target city. In the following text, each step of the methodology is applied to Chengdu for the selection of the best practices as a reference in promoting low-carbon city development.

3.1 Establishment of a case base

A main consideration in the establishment of a case base of low-carbon cities that provides sufficient practices on low-carbon city development is that the cities should have completed or are in the progress of undertaking the development of a low-carbon city, such that they have generated good practices on developing a low-carbon city.

Beginning in July 2010, NDRC in China has initiated three batches of low-carbon pilot provinces and cities to determine feasible local policies or actions that can be replicated at a large scale. To date, 87 low-carbon pilot regional areas exist, and these include 6 provinces, 4 provincial-level municipalities, 69 prefecture-level cities, 4 county-level cities, 3 countries, and 1 district. The third batch of pilot areas was launched in 2017. To collect and diffuse useful low-carbon practices, this study focuses on the two initial batches, which include 6 provinces, 4 provincial-level municipalities, and 32 prefecture-level cities, which were implemented in 2010 and 2012. In addition, cities and provinces have many unique features. Hence, this study selects 34 cities (i.e., Hulun Buir, Urumqi, Jilin, Qinhuangdao, Beijing, Tianjin, Baoding, Jinchang, Shijiazhuang, Jincheng, Qingdao, Yan'an, Huai'an, Zhenjiang, Suzhou, Guangyuan, Chizhou, Shanghai, Wuhan, Hangzhou, Chongqing, Jingdezhen, Ningbo, Wenzhou, Zunyi, Nanchang, Xiamen, Guiyang, Ganzhou, Nanping, Kunming, Guilin, Guangzhou, and Shenzhen) in the two initial batches to establish a case base. The 34 low-carbon pilot cities are located in different regions of China and represent the majority of inhabited areas with different features.

3.2 Case retrieval for Chengdu City

3.2.1 Similarity level between Chengdu and low-carbon pilot cities

Case retrieval is conducted by measuring the similarity level between Chengdu and cities in the case base. The performance data of each feature are obtained from 2016. The local similarity between Chengdu and a city in the case base for each feature is obtained by using Eqs. (1)–(3). Global similarity is calculated using Eq. (7), and the results are shown in Table 4. In the process of demonstrating the

Table 4 Similarity levels between Chengdu and 34 cities in China

City	Similarity level
Nanchang	0.9183
Huai'an	0.9147
Wenzhou	0.9052
Ningbo	0.8871
Wuhan	0.8870
Hangzhou	0.8848
Qingdao	0.8719
Chongqing	0.8563
Zhenjiang	0.8432
Suzhou	0.8362
Jingdezhen	0.8348
Guilin	0.8256
Chizhou	0.8176
Kunming	0.8095
Guangyuan	0.8039
Baoding	0.8017
Shijiazhuang	0.7994
Guiyang	0.7982
Qinhuangdao	0.7963
Zunyi	0.7917
Tianjin	0.7904
Ganzhou	0.7870
Jilin	0.7826
Xiamen	0.7821
Jinchang	0.7466
Hulun Buir	0.7417
Shanghai	0.7415
Nanping	0.7354
Yan'an	0.7335
Jincheng	0.7218
Guangzhou	0.6706
Urumqi	0.6514
Beijing	0.6291
Shenzhen	0.5192

proposed CBR system, we consider that features have equal weights, which indicates that every feature has an equal influence on determining the similarity level (Marlin et al., 1986; Savageau and Boyer, 1993; Rondinelli and Vastag, 1998; Huggins, 2000). Compared with the black box calculation of principal component analysis, equal weighting is relatively simpler and more transparent (Beaverstock et al., 1999), and its results can be easily interpreted.

3.2.2 Selection of the best practices of low-carbon city development for Chengdu

(1) Selection of low-carbon city practices

To identify existing low-carbon city development practices, a comprehensive literature review is conducted on 39 policy and regulation papers relevant to the practice of low carbon in China. As a result, 49 low-carbon city practices are obtained and categorized into 8 groups, namely, develop a low-carbon economy (P1), optimize the energy structure and improve energy efficiency (P2), conduct demonstration projects (P3), increase the carbon sink (P4), develop low-carbon buildings (P5), develop low-carbon transportation (P6), develop low-carbon life (P7), and low-carbon city management (P8). The selected low-carbon practices are shown in Table 5.

(2) Giving scores to low-carbon city practices

The rating method in this study is defined as city j adopts and gives practice i a score of “1.” Otherwise, city j gives practice i a score of “0” when it is not adopted.

(3) Combining the scores of each practice given by low-carbon pilot cities

Weighted sum recommender (WSR) is widely regarded as an effective top-N algorithm and has produced good results in the top-N recommendation task (Valcarce et al., 2018). This study uses the WSR algorithm to combine the scores of practices adopted by the 10 most similar cities in the following manner.

$$r_{C_0,k}=\frac{\sum_{C_i'\in I} sim(C_0,C_i')r_{C_i',k}}{\sum_{C_i'\in I} sim(C_0,C_i')}, \tag{8}$$

where $r_{C_0,k}$ denotes the rating score of low-carbon city practice k given by target city C_0, I denotes the set of top 10 cities that are most similar to target city C_0, C_i' is a case city that belongs to set I, and $r_{C_i',k}$ presents the rating score of low-carbon city practice k given by case city C_i'.

This study applies Eq. (8) to combine the ratings of the most similar cities, and the results are shown in Table 6.

(4) Best practices for Chengdu in promoting low-carbon city development

On the basis of the combined rated values of each practice, this study filters practices with rating scores lower than 0.5, which means that these practices are not recommended for Chengdu. This study classifies other practices into two groups, namely, highly recommended practices with integrated rating scores equal to or higher than 0.75 and recommended practices with integrated rating scores higher than 0.5 and lower than 0.75. The recommendation results of best practices for Chengdu in promoting low-carbon city development are shown in Table 7.

3.3 Case adaption and retention

After case retrieval, this study selects two groups of practices, namely, highly recommended and recommended, for Chengdu to initiate low-carbon city development. These practices can be adopted as a reference for Chengdu when making low-carbon development strategies. The government of Chengdu can revise these retrieved practices to make them suitable for Chengdu in consideration of local conditions. To improve the performance of the proposed methodology, Chengdu can keep records on the implementation of these best practices and add them to the case base and best practice repository.

4 Discussions

This study identifies two types of features, namely, impact features of carbon emission and city context features, through a literature review to systematically and holistically characterize cities. As shown in Tables 1 and 2, four city context features and 19 impact features of carbon emission are available in three different formats. These features cover almost all existing principal information used for characterizing cities but may not include new emerging important features in the future. However, this problem can be resolved by the flexibility of the proposed methodology. The methodology allows users to add new emerging key features into the feature set. The addition of new features can be performed in combination with the empirical knowledge of users. In this study, equal weights are assigned to all features when they are utilized to measure similarity levels between cities. In reality, different features have different influence levels on city similarity, and different weights can be assigned to features to differentiate the importance of various features. The flexibility of CBR allows decision makers to assign weights to these features based on their objective judgement. Previous studies have established several methods, such as analytical hierarchy process, entropy method, genetic algorithms, and neural networks. Decision makers can use proper methods to assign weights to features when applying the proposed methodology or allocate weights with subjective methods based on their own experience.

Table 5 Low-carbon city practices selected in this study

Practice category	Practice	Cities that adopted the practice
Develop a low-carbon economy (P1)	Promote the development of a low-carbon industry (P11)	Tianjin, Chongqing, Shenzhen, Hangzhou, Nanchang, Baoding, Jincheng, Hulun Buir, Shijiazhuang, Qinhuangdao, Suzhou, Huai'an, Zhenjiang, Ningbo, Wenzhou, Nanping, Jingdezhen, Ganzhou, Chizhou, Wuhan, Guangzhou, Guilin, Guangyuan, Yan'an, Jinchang, Urumqi, Beijing, Jilin, Shanghai
	Promote the upgrading of traditional industries (P12)	Tianjin, Shenzhen, Hangzhou, Nanchang, Baoding, Jincheng, Shijiazhuang, Qinhuangdao, Zhenjiang, Wenzhou, Nanping, Jingdezhen, Ganzhou, Guangyuan, Urumqi, Jilin
	Develop the tertiary industry (P13)	Tianjin, Chongqing, Shenzhen, Xiamen, Nanchang, Guiyang, Jincheng, Shijiazhuang, Qinhuangdao, Suzhou, Huai'an, Zhenjiang, Ningbo, Wenzhou, Nanping, Jingdezhen, Ganzhou, Qingdao, Chizhou, Wuhan, Guangzhou, Guilin, Guangyuan, Zunyi, Yan'an, Jinchang, Jilin, Shanghai
	Develop low-carbon agriculture (P14)	Tianjin, Chongqing, Shenzhen, Nanchang, Baoding, Jincheng, Hulun Buir, Qinhuangdao, Zhenjiang, Jingdezhen, Ganzhou, Qingdao, Wuhan, Guilin, Guangyuan, Yan'an, Jinchang, Jilin
	Shut down heavy energy-consumption enterprises (P15)	Chongqing, Shijiazhuang, Suzhou, Zhenjiang, Ningbo, Ganzhou, Wuhan, Guangzhou, Zunyi, Urumqi, Beijing, Shanghai
	Promote the development of the photovoltaic industry (P16)	Nanchang, Baoding, Huai'an, Zhenjiang, Ningbo, Wuhan, Guangyuan, Yan'an, Jinchang, Urumqi
Optimize the energy structure and improve energy efficiency (P2)	Increase the utilization proportion of natural gas (P21)	Tianjin, Shenzhen, Nanchang, Zhenjiang, Ningbo, Wenzhou, Jingdezhen, Guangzhou, Guangyuan, Yan'an, Jinchang, Urumqi, Beijing, Shanghai
	Promote the development of hydropower projects (P22)	Chongqing, Zhenjiang, Wenzhou, Ganzhou, Guangyuan, Zunyi, Kunming, Yan'an, Jinchang
	Promote the development of wind-power projects (P23)	Chongqing, Shenzhen, Huai'an, Zhenjiang, Ningbo, Wenzhou, Ganzhou, Chizhou, Zunyi, Kunming, Yan'an, Jinchang, Urumqi, Shanghai
	Promote the exploitation and utilization of biomass energy (P24)	Chongqing, Shenzhen, Nanchang, Baoding, Huai'an, Ningbo, Wenzhou, Jingdezhen, Chizhou, Wuhan, Guangyuan, Zunyi, Yan'an, Jinchang, Urumqi, Shanghai
	Develop projects of landfill gas recovery and power generation (P25)	Chongqing, Shenzhen, Hangzhou, Baoding, Jincheng, Zhenjiang, Kunming
	Launch cogeneration power plants (P26)	Chongqing, Baoding, Wenzhou, Chizhou, Yan'an, Urumqi, Shanghai
	Promote the utilization of solar power (P27)	Shenzhen, Hangzhou, Nanchang, Baoding, Wenzhou, Jingdezhen, Ganzhou, Guangyuan, Zunyi, Kunming, Shanghai
	Promote the exploitation and utilization of renewable energy and new energy (P28)	Tianjin, Xiamen, Nanchang, Guiyang, Jincheng, Shijiazhuang, Qinhuangdao, Suzhou, Huai'an, Zhenjiang, Wenzhou, Nanping, Qingdao, Guangzhou, Guilin, Jinchang, Beijing, Shanghai
	Promote energy saving and emission reduction in industries (P29)	Tianjin, Shenzhen, Xiamen, Hangzhou, Nanchang, Guiyang, Baoding, Jincheng, Hulun Buir, Ningbo, Nanping, Ganzhou, Qingdao, Chizhou, Guilin, Guangyuan, Zunyi, Jinchang, Shanghai

(*Continued*)

Practice category	Practice	Cities that adopted the practice
Conduct demonstration projects (P3)	Low-carbon industry demonstration (P31)	Tianjin, Xiamen, Hangzhou, Nanchang, Nanping, Jingdezhen, Guangyuan, Urumqi, Beijing, Shanghai
	Low-carbon building demonstration (P32)	Tianjin, Hangzhou, Nanchang, Baoding, Jincheng, Zhenjiang, Ningbo, Guangyuan, Zunyi, Urumqi, Beijing
	Low-carbon transportation demonstration (P33)	Tianjin, Hangzhou, Nanchang, Hulun Buir, Nanping, Guilin, Zunyi, Urumqi
	Low-carbon enterprise demonstration (P34)	Shenzhen, Nanchang, Jincheng, Zhenjiang, Wenzhou, Jingdezhen, Guilin, Urumqi,
	Low-carbon industrial park demonstration (P35)	Tianjin, Shenzhen, Hangzhou, Jincheng, Wenzhou, Ganzhou, Qingdao, Chizhou, Wuhan, Urumqi, Beijing
	Low-carbon community demonstration (P36)	Tianjin, Shenzhen, Xiamen, Hangzhou, Nanchang, Guiyang, Baoding, Jincheng, Suzhou, Zhenjiang, Wenzhou, Jingdezhen, Ganzhou, Qingdao, Chizhou, Guangzhou, Guilin, Zunyi, Kunming, Urumqi, Beijing, Shanghai
	Low-carbon town demonstration (P37)	Tianjin, Hangzhou, Zhenjiang, Wenzhou, Ganzhou, Qingdao, Guangyuan, Zunyi, Urumqi
Increase the carbon sink (P4)	Increase forest carbon sink (P41)	Tianjin, Chongqing, Shenzhen, Xiamen, Hangzhou, Nanchang, Guiyang, Jincheng, Hulun Buir, Shijiazhuang, Suzhou, Ningbo, Wenzhou, Nanping, Jingdezhen, Ganzhou, Qingdao, Wuhan, Guangzhou, Guilin, Guangyuan, Zunyi, Kunming, Yan'an, Jinchang, Urumqi, Beijing, Shanghai
	Promote urban afforestation construction (P42)	Chongqing, Shenzhen, Baoding, Jincheng, Suzhou, Zhenjiang, Wenzhou, Qingdao, Wuhan, Guangzhou, Guangyuan, Yan'an, Urumqi
	Increase wetland carbon sink (P43)	Hangzhou, Hulun Buir, Suzhou, Zhenjiang, Wenzhou, Qingdao, Kunming, Beijing
Develop low-carbon buildings (P5)	Promote green and energy-saving buildings (P51)	Tianjin, Chongqing, Shenzhen, Xiamen, Hangzhou, Nanchang, Guiyang, Baoding, Jincheng, Hulun Buir, Shijiazhuang, Huai'an, Zhenjiang, Ningbo, Wenzhou, Nanping, Ganzhou, Qingdao, Chizhou, Guangzhou, Guilin, Kunming, Yan'an, Jinchang, Urumqi, Beijing, Shanghai
	Promote energy-saving building standards (P52)	Chongqing, Hangzhou, Nanchang, Guiyang, Baoding, Jincheng, Hulun Buir, Shijiazhuang, Huai'an, Zhenjiang, Qingdao, Wuhan, Guangyuan, Zunyi, Yan'an, Urumqi, Beijing, Shanghai
	Promote new energy-saving building materials (P53)	Chongqing, Shenzhen, Hangzhou, Nanchang, Guiyang, Huai'an, Jingdezhen, Ganzhou, Chizhou, Guilin, Guangyuan, Zunyi, Kunming, Urumqi, Beijing, Shanghai
	Promote ground-source heat pump technology (P54)	Chongqing, Shenzhen, Xiamen, Hangzhou, Nanchang, Baoding, Jincheng, Shijiazhuang, Suzhou, Chizhou, Wuhan, Zunyi
	Install solar photovoltaic systems on the roof of buildings (P55)	Shenzhen, Hangzhou, Nanchang, Baoding, Jincheng, Hulun Buir, Shijiazhuang, Suzhou, Jingdezhen, Ganzhou, Chizhou, Zunyi, Kunming
	Reduce the energy consumption of government office buildings (P56)	Shenzhen, Nanchang, Guiyang, Hulun Buir, Shijiazhuang, Huai'an, Zhenjiang, Jingdezhen, Ganzhou, Chizhou, Guangyuan, Zunyi, Yan'an, Shanghai
	Conduct energy-saving upgrading in existing buildings (P57)	Baoding, Jincheng, Shijiazhuang, Suzhou, Huai'an, Zhenjiang, Ningbo, Wenzhou, Jingdezhen, Qingdao, Wuhan, Guangzhou, Guilin, Guangyuan, Zunyi, Yan'an, Urumqi, Shanghai
	Promote the utilization of efficient energy-saving lighting systems (P58)	Nanchang, Jingdezhen, Chizhou, Wuhan, Guangzhou, Guangyuan, Zunyi, Yan'an, Urumqi, Shanghai

(*Continued*)

Practice category	Practice	Cities that adopted the practice
Develop low-carbon transportation (P6)	Prioritize the construction of public transportation (P61)	Tianjin, Chongqing, Shenzhen, Xiamen, Hangzhou, Guiyang, Baoding, Jincheng, Hulun Buir, Shijiazhuang, Suzhou, Huai'an, Zhenjiang, Ningbo, Wenzhou, Nanping, Ganzhou, Qingdao, Wuhan, Guangzhou, Guilin, Zunyi, Kunming, Yan'an, Jinchang, Urumqi, Beijing, Shanghai
	Construct urban rail transit (P62)	Tianjin, Chongqing, Hangzhou, Guiyang, Shijiazhuang, Huai'an, Ningbo, Nanping, Guangzhou, Urumqi, Beijing, Shanghai
	Promote the use of energy-saving and environment-friendly vehicles (P63)	Chongqing, Shenzhen, Xiamen, Hangzhou, Nanchang, Guiyang, Baoding, Jincheng, Hulun Buir, Shijiazhuang, Suzhou, Huai'an, Zhenjiang, Nanping, Jingdezhen, Ganzhou, Qingdao, Chizhou, Wuhan, Guangzhou, Guilin, Kunming, Yan'an, Jinchang, Urumqi, Beijing, Shanghai
	Construct intelligent transportation network systems (P64)	Chongqing, Shenzhen, Xiamen, Nanchang, Jincheng, Suzhou, Huai'an, Wenzhou, Jingdezhen, Qingdao, Wuhan, Guilin, Zunyi, Kunming, Jinchang, Beijing
	Phase out high-pollution vehicles (P65)	Nanchang, Baoding, Jincheng, Suzhou, Zhenjiang, Zunyi, Yan'an, Urumqi, Shanghai
Develop low-carbon life (P7)	Guide the public to use green forms of transport (P71)	Tianjin, Hangzhou, Guiyang, Baoding, Hulun Buir, Shijiazhuang, Suzhou, Wenzhou, Nanping, Zunyi, Kunming, Jinchang, Shanghai
	Develop low-carbon consumption habits (P72)	Tianjin, Chongqing, Shenzhen, Xiamen, Baoding, Shijiazhuang, Suzhou, Wenzhou, Nanping, Jingdezhen, Qingdao, Guangzhou, Guilin, Zunyi, Kunming, Jinchang, Urumqi, Shanghai
	Raise residents' awareness of low-carbon life (P73)	Chongqing, Shenzhen, Hangzhou, Nanchang, Guiyang, Baoding, Jincheng, Shijiazhuang, Qinhuangdao, Suzhou, Zhenjiang, Ningbo, Wenzhou, Nanping, Jingdezhen, Ganzhou, Qingdao, Wuhan, Guilin, Zunyi, Kunming, Jinchang, Urumqi, Beijing, Shanghai
	Collect and dispose household garbage (P74)	Xiamen, Hangzhou, Hulun Buir, Shijiazhuang, Suzhou, Zhenjiang, Ningbo, Qingdao, Guangzhou, Guilin, Zunyi, Kunming, Urumqi, Beijing, Shanghai
Low-carbon city management (P8)	Establish low-carbon product certification (P81)	Tianjin, Chongqing, Shenzhen, Hangzhou, Baoding, Suzhou, Zhenjiang, Wenzhou, Wuhan, Guilin, Kunming, Shanghai
	Establish a low-carbon development research center (P82)	Tianjin, Chongqing, Hangzhou, Nanchang, Shijiazhuang, Zhenjiang, Wenzhou, Qingdao
	Establish a statistical management system for carbon emission (P83)	Tianjin, Chongqing, Xiamen, Guiyang, Jincheng, Shijiazhuang, Qinhuangdao, Suzhou, Huai'an, Zhenjiang, Ningbo, Wenzhou, Nanping, Ganzhou, Qingdao, Wuhan, Guangzhou, Guilin, Guangyuan, Zunyi, Yan'an, Jinchang, Beijing, Shanghai
	Carry out trials for trading carbon emission rights (P84)	Tianjin, Chongqing, Shenzhen, Guiyang, Hulun Buir, Suzhou, Huai'an, Wenzhou, Wuhan, Guangzhou, Guilin, Zunyi, Beijing, Shanghai
	Establish a performance evaluation mechanism for low-carbon development (P85)	Tianjin, Shenzhen, Guiyang, Suzhou, Wenzhou, Nanping, Ganzhou, Qingdao, Wuhan, Guangzhou, Guilin, Guangyuan, Zunyi, Yan'an, Jinchang, Beijing, Shanghai
	Set regulations on low-carbon development (P86)	Shenzhen, Xiamen, Nanchang, Guiyang, Jincheng, Zhenjiang, Ningbo, Nanping, Ganzhou, Qingdao, Wuhan, Guangzhou, Jinchang
	Make low-carbon city development plans (P87)	Guiyang, Jincheng, Zhenjiang, Ningbo, Nanping, Qingdao, Guangzhou, Jinchang

Table 6 Results of the combined ratings of the top 10 most similar cities

Practice	Combined rating	Practice	Combined rating	Practice	Combined rating
P11	0.9010	P33	0.2048	P62	0.5067
P12	0.4034	P34	0.3029	P63	0.7964
P13	0.8995	P35	0.4031	P64	0.7030
P14	0.4971	P36	0.5974	P65	0.2950
P15	0.4895	P37	0.3981	P71	0.2983
P16	0.5055	P41	0.8003	P72	0.3941
P21	0.4036	P42	0.5906	P73	0.8961
P22	0.2958	P43	0.4931	P74	0.4910
P23	0.5005	P51	0.8043	P81	0.5920
P24	0.6097	P52	0.7015	P82	0.5996
P25	0.2935	P53	0.4059	P83	0.7952
P26	0.2001	P54	0.4978	P84	0.4997
P27	0.3076	P55	0.2998	P85	0.3976
P28	0.6008	P56	0.3039	P86	0.5006
P29	0.4046	P57	0.6980	P87	0.2955
P31	0.2048	P58	0.2050		
P32	0.4013	P61	0.8957		

5 Conclusions

Learning from previous successful experience is an effective approach to promote low-carbon city development. However, no effective tools are available for low-carbon city developers to reuse and benefit from past experience. This research introduces a methodology based on CBR for decision makers to determine the best practices suitable for use as a reference when embarking on low-carbon city development. The CBR-based methodology has three main components, namely, case presentation, case retrieval, and case adaption and retention. This study selects two features, namely, impact features of carbon emission and city context features, because decision makers consider carbon emission factors and city contextual information. We apply the proposed CBR-based methodology in identifying the best practices with Chengdu (capital of Sichuan Province in China) as a case example. The results suggest that the CBR system demonstrates good performance in selecting similar low-carbon cities for reference by a specific city.

The proposed recommendation system provides the following contributions. The application of the CBR-based methodology can help governments formulate low-carbon city development strategies. The proposed methodology

Table 7 Recommendation results of the best practices for Chengdu

Recommendation priority	Practice	Rated value
Highly recommended practices (rated value ⩾ 0.75)	P11 Promote the development of a low-carbon industry	0.9010
	P13 Develop the tertiary industry	0.8995
	P73 Raise residents' awareness of low-carbon life	0.8961
	P61 Prioritize the construction public transportation	0.8957
	P51 Promote green and energy-saving buildings	0.8043
	P41 Increase forest carbon sink	0.8003
	P63 Promote the use of energy-saving and environment- friendly vehicles	0.7964
	P83 Establish a statistical management system for carbon emission	0.7952
Recommended practices (0.75 > rated value > 0.5)	P64 Construct intelligent transportation network systems	0.7030
	P52 Promote energy-saving building standards	0.7015
	P57 Conduct energy-saving upgrading in existing buildings	0.6980
	P24 Promote the exploitation and utilization of biomass energy	0.6097
	P28 Promote the exploitation and utilization of renewable and new energy	0.6008
	P82 Establish a low-carbon development research center	0.5996
	P36 Low-carbon community demonstration	0.5974
	P81 Establish low-carbon product certification	0.5920
	P42 Promote urban afforestation construction	0.5906
	P62 Construct urban rail transit	0.5067
	P16 Promote the development of the photovoltaic industry	0.5054
	P86 Make regulations on low-carbon development	0.5006
	P23 Promote the development of wind power projects	0.5005

can reduce the time and budget required when a city is engaged in the planning of reducing carbon emissions at the city level. The application of the proposed methodology can eliminate the redundant search for reports on pilot cities for previous related experience as a reference. Second, this study introduces two types of features, namely, impact features of carbon emission and city context features, to present cities. These features should be considered when formulating strategies of low-carbon city development. Among the features for case presentation, city context features can benefit other studies on urban areas.

This study focuses on the early stage of selecting useful previous experience for a specific city undergoing low-carbon development. In the future, more cases can be added to the case base to enable the expanded case base to have better representation of low-carbon city cases and best practices. The intrinsic relationships among city context features, impact features of carbon emission, and best practices should also be investigated, and the reasoning results should be provided for informed decisions in low-carbon city development.

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