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EDITED BY
Wendong Wei,
Shanghai Jiao Tong University, China

REVIEWED BY
Liu Hanbin,
Fudan University, China
Pengfei Zhang,
Shandong University, China

*CORRESPONDENCE
Xin Nie,
toefl678@163.com
Han Wang,
hanwang@gxu.edu.cn

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Environmental dilemma and sustainable development of resource-based cities: A case study from northeast china

Yiting Qing[1], Wei Guo[2], Gaohang Cao[3], Yu Qin[4], Xin Nie[5]* and Han Wang[5]*

[1]Sino-Danish College, University of Chinese Academy of Sciences, Institutes of Science and Development, Chinese Academy of Sciences, Beijing, China, [2]China Center for Urban Development, National Development and Reform Commission Beijing China, Department of Energy and Power Engineering, Tsinghua-BP Clean Energy Center, Tsinghua University, Beijing, China, [3]Department of Economics, Party School of the Central Committee of the Chinese Communist Party, Beijing, China, [4]Center for Energy and Environmental Policy Research, Beijing Institute of Technology, Beijing, China, [5]School of Public Administration of Guangxi University, China Center for Agricultural Policy (CCAP), School of Advanced Agricultural Sciences, Peking University, Beijing, China

With ambitious carbon peak and carbon neutral targets, China has to realize it relies heavily on significant reductions in energy-related carbon emissions. Therefore, as the largest contributing region, resource-based cities (RBCs) must achieve an energy transition. Unfortunately, these cities are facing serious environmental problems. The aim of this study is to analyze the development history and problems of RBCs by using the example of the Northeast region. The results show the reasons blocking the green development of these cities include management policies and life cycles. This implies the management of RBCs needs to develop toward a win-win situation of industrial transformation and ecological protection. Finally, some policy recommendations are proposed to achieve emission reduction and sustainable development.

KEYWORDS

resource-based cities, sustainable development, northeast China, environmental dilemmas, green transformation

Introduction

RBCs were once regarded as cities with a single extractive industry as the pillar industry and dominated by one industrial company. Moreover, they have been essential for industrialization and urbanization in China. Generally, they are also called mining towns or RBCs (Yan et al., 2019). In recent years, due to the decrease in recoverable resources, it has been more and more difficult to exploit the resources. With the pressure of survival and development, the exploitation intensity of natural resources has increased, and thus resource exploitation has transferred from developed countries to many developing ones (He et al., 2017; Wang Y. et al., 2020). However, due to the fragile economic foundation of these developing countries, resource development causes many

economic problems, such as low per capita GDP, unbalanced economic and industrial structure, heavy labor pressure, and reduced tax revenue, hurting the long-term sustainability of the cities. (Li et al., 2013; Li et al., 2015; He et al., 2017; Li and Dewan, 2017; Ruan et al., 2020). Besides, large-scale resource extraction can also bring serious environmental problems to RBCs, including accelerated resource extraction and depletion, and increased pollution levels in the existing environment (Krueger and Grossman, 1991). Fossil energy extraction, for example, on the one hand, creates a large amount of solid waste, leading to surface and groundwater pollution and air pollution if not properly treated (Wiedensohler et al., 2009). On the other hand, it will cause ground collapse, ground fractures, and other geoenvironmental high-risk areas to expand (Tan J. et al., 2017), causing waste of land resources and further increasing environmental pressure (Zoundi, 2017). These crises threaten the development of RBCs in many developing countries. Some scholars (Xia et al., 2021) mentioned that the sustainable development of RBCs needs to be realized through a transformation because the resources are non-renewable. Naturally, how to solve the current problems of RBCs and finally realize the transformation of RBCs has become a hot issue.

In the context of carbon peak and carbon neutrality targets, the relationship between RBCs and carbon emissions has received much academic attention. However, the impact of RBCs development on carbon emissions is uncertain. On the one hand, Hou et al. (2018) argued that the development of RBCs was accompanied by a heavy reliance on fossil energy and an irrational industrial structure, i.e., the "lock-in effect". This implies the sloppy development pattern caused by this effect will further promote carbon emissions (Sun Q. et al., 2021). On the other hand, Zhou et al. (2022) suggested that RBCs with low carbon as the goal can enhance carbon emission efficiency, which will help to promote carbon emission reduction and achieve carbon peak and carbon neutrality in advance. Similar findings can be found in Zhang M. et al (2022), and Zheng and Ge (2022). Many scholars support this view and argue that China's achievement of carbon peak and carbon neutrality depends on RBC's low-carbon development (Ma et al., 2021; Guo, 2021; Liao et al., 2022). According to statistics, RBCs consume 60% of national energy (Fong et al., 2008; Zhang H. et al., 2022). The per capita carbon emission of RBCs is twice the national average. Besides, the carbon emission intensity of RBCs is 1.5 times the national average (Sun X. et al., 2021). Therefore, it is significant to achieve sustainable development through improving energy resilience among RBCs (Tan P. et al., 2017, 2020) under the carbon peak and carbon neutrality targets.

This study chooses Northeast China as a typical case to study China's RBCs. First and foremost, Northeast China not only includes many representative RBCs (Wang Y. et al., 2020) but also has to bear relatively high pressure on environmental governance, similar to other RBCs. Up to now, there are

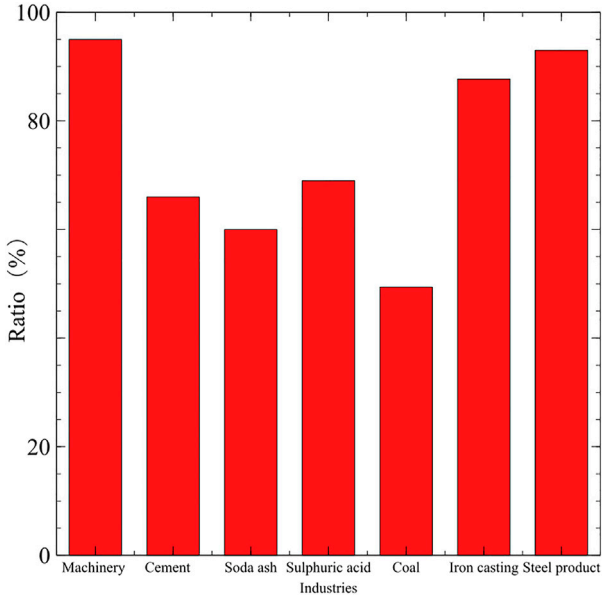

FIGURE 1
Ratio of resources in Northeast China to national output in 1940s.

39 RBCs in the urban agglomeration of Northeast China, with a single economic structure, dual management system, and differentiated urban functions (Tan J. et al., 2017). At the same time, according to the list of difficulties in transforming RBCs published by Peking University in 2017, the top four cities are located in Northeast China. To some extent, it reflects that the RBCs in Northeast China face relatively high transformation pressure. There are still some undiscovered and unsolved deep-seated contradictions to be solved. Hence, the ecological transformation of RBCs in Northeast China is imminent (Wang et al., 2020a, b). Secondly, the Chinese government has constantly been attaching great importance to urban construction in Northeast China, making the case particular. The Chinese government has promulgated a series of policies targeting the development of this area. However, as in many other countries rich in natural resources, the resources of these cities have not been the motivation for their development, but have left them far behind other cities, thus seriously hindering the overall progress of the country (Sachs and Warner, 2001; Chen et al., 2018; Ruan et al., 2020).

Therefore, this paper also used case studies (Omolade et al., 2019; John and Tasciotti, 2020; Nel and Connelly, 2020) to expound on the typical RBCs and analyze their dilemma and solutions for reference, with the following two contribution. First, compared to Reid and Gartell. (2013) and Mitchell and O'Neill. (2016), this paper can provide a more comprehensive overview of the development history of the Northeast region. Second, although the quantitative research methods used in

TABLE 1 List of RBCs in northeast China.

Prov-ince	Prefecture level division	County-level city	Counties (autonomous regions and forest areas)	Municipal district
Liaoning (15)	Fuxin, Fushun, Benxi, Anshan, Panjin and Huludao	Beipiao city, Diaobingshan, Fengcheng, dashiqiao city	Kuandian Manchu Autonomous County, Yixian County	Changling District, Nanpiao District, Yangjiazhangzi Development Zone
Jilin (11)	Songyuan, Jilin *, Liaoyuan, Tonghua, baishan city *, Yanbian Korean Autonomous Prefecture	Kyushu, shulan city and Dunhua *	Wangqing county *	Erdaojiang district
Heilongjiang (11)	Heihe *, Daqing, Yichun *, hegang, Shuangyashan, qitaihe city, Jixi, Mudanjiang * and Daxinganling *	Shangzhi city *, wudalianchi city *		
Eastern Inner Mongolia (2)	Chifeng and Hulunbeier			

The cities marked with * are forest industry cities.

Zhang M. et al. (2022) (Zhang H. et al., 2022) and Zheng and Ge. (2022) did not be used, this paper, similar to Sunikka (2006) and Liu and Gallagher (2010), is an exploratory approach to considering what policies governments in developing countries can adopt to guide the development of RBCs in the context of the "paradox" of economic transformation and environmental protection.

The rest of this paper is structured as follows. The second part is a case study including the basic situation, the dilemma, and underlying causes in Northeast China. The third part is policy recommendations. The Final is the conclusion.

Case study

Basic situation of northeast china

Northeast China consists of three provinces and part of an autonomous region: Liaoning, Jilin, Heilongjiang, and eastern Inner Mongolia. The land area is 1.45 million square kilometers, and the total population is up to 120 million in this region (China Bureau of Statistics, 2019). As shown in Figure 1, resources in Northeast China accounted for a high proportion of national output in the 1940s. For this reason, Northeast China is known as China's old heavy industry base.

According to the ***National sustainable development plan for resource-based cities*** (***2013–2020***) (State Council, 2013), there are 39 RBCs in Northeast China, and their distribution is shown in Table 1.

The dilemma of transformation and development in northeast China

Reviewing the development process of RBCs in Northeast China, there are the following development problems.

1) Northeast China has a large number of RBCs with diverse types and different development stages. In terms of resource types, the RBCs in Northeast China can be divided into coal-based cities, including Fushun; oil-based cities, such as Daqing, Songyuan, and Panjin; cities dominated by iron and steel industry, including Fuxin; dominated by nonferrous metal mineral RBCs and nonmetal RBCs, including Huludao, and Tieli city; forestry industry cities, including Yichun and Heihe. At the same time, from the development status of these cities, according to the division of RBCs in the Plan, 39 RBCs in Northeast China include two growing resource cities, 13 mature resource cities, 19 declining resource cities, and five renewable resource cities, as shown in Table 2.
2) RBCs in Northeast China have economic problems such as a single industrial structure and slow regional economic growth. At first, relying on unique natural resources, Northeast China was devoted to developing many serious pollution industries, such as metallurgy, machinery, and building materials. At the same time, other industrial sectors were still unchanged. It results in a single industrial structure, as shown in Figure 2.

After more than half a hundred years of exploitation and excavation, many RBCs in Northeast China began to experience resource depletion, economic recession, and population loss (Yang et al., 2022), and the low learning and innovation capacity hindered the development of alternative industries (Yu and Cheng, 2016). These problems led to the bankruptcy and relocation of many industrial enterprises (Yang et al., 2022), causing sharp urban unemployment and continuous urban population loss (Yu and Cheng, 2016). Meanwhile, most cities in Northeast China do not have medium and long-term development plans and cannot implement new energy projects to improve energy efficiency due to policy conflicts (Yu and Cheng, 2016). In addition, the labor force shortage has emerged,

TABLE 2 Classification of RBCs in northeast China.

Prov-ince	Prefecture level division	County-level city	Counties (autonomous regions and forest areas)	Municipal district
Growth (2)	Songyuan City, Hulunbeier City			
Mature (13)	Benxi, Jilin, Yanbian Korean Autonomous Prefecture, Heihe, Daqing, Jixi, Mudanjiang and Chifeng	DiaoBingshan City, Fengcheng City, Shangzhi City	DiaoBingshan City, Fengcheng City, Shangzhi City	
Recess-ion (19)	Fuxin, Fushun, Liaoyuan, baishan city, Yichun, hegang, Shuangyashan, Qitaihe city and Daxinganling	Beipiao city, Jiutai, shulan city, Dunhua, Wudalianchi city	Wangqing county	Changling District, Nanpiao District, Yangjiazhangzi Development Zone, Erdaojiang District
Regene-ration (5)	.Anshan, Panjin, Tonghua and Huludao	Dashiqiao city		

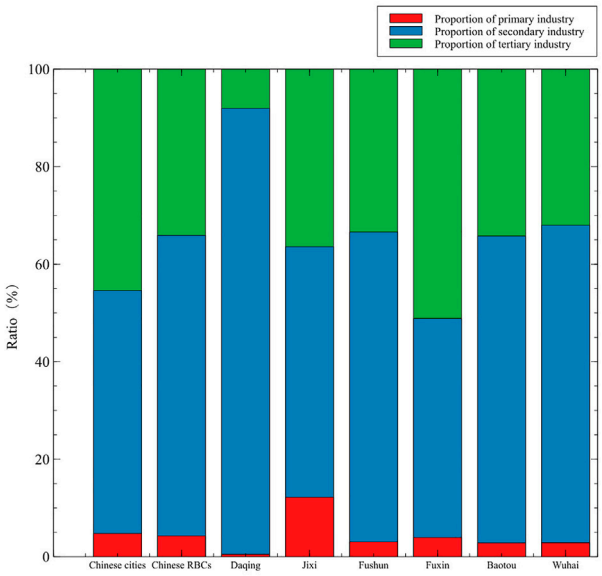

FIGURE 2
Industrial proportion of RBCs in northeast China in 2001.

and the alternative for high energy-consuming industries is still too immature to make up for economic losses, which comprehensively leads to the slow growth of the regional economy.

3) Environmental problems such as land collapse and soil erosion are common in RBCs in Northeast China. For coal mining, underground mining was carried out around mines in Northeast China, resulting in large-scale surface subsidence and destruction of various buildings, roads, bridges, and farmlands. According to the survey, at the end of 1995, the area of land collapsed by state-owned coal mines in China was about 350,000 ha. Taking Liaoyuan for instance, the subsidence area, mined-out area, and unstable subsidence area formed by history were 18.95, 14.58, and 15.66 square kilometers, respectively (Jilin Provincial government, 2016). Similarly, the coal mined-out area of Shuangyashan is 116.6 square kilometers, and the subsidence area was 62 square kilometers, involving 68,000 residents. Moreover, Datong produces two billion tons of coal annually and forms nearly 45,000 ha of mined-out areas. In addition, environmental problems such as industrial pollution, landslides, and soil erosion (Tan P. et al., 2017) in large areas of river basins are also severe. Taking Jilin Province as an example, the monitoring results show that the soil erosion area in 2019 was 41,800 square kilometers, accounting for 21.95% of the province's total land area (Jilin Provincial government, 2020).

Dilemma causes

The dilemma faced by RBCs in Northeast China is caused by two factors. On the one hand, the plight of RBCs in Northeast China is closely related to management policies. As the first region in China to implement a planned economy, Northeast China, with its industrial base and a large number of natural resources, has undertaken most of the industrial production tasks of the new China since the 1950s (Li et al., 2013). Under the guidance of the planned economy, resource exploitation in the Northeast became more frequent in order to secure the needs of national economic development. Subsequently, reform and opening up emerged in China's southeast coastal regions. The Northeast failed to effectively attract foreign investment because of geographic constraints resulting in fewer new industrial layouts and a large population loss to the southeastern coastal regions (Yang et al., 2018). In the 1990s, China started a wave of state-owned enterprise reforms. This directly led to the layoff of eight million workers in Northeast China (accounting for nearly 30% of the country), making the development of this area increasingly difficult (Mak, 2008).

TABLE 3 Industrial characteristics and pillar industries of four types of RBCs.

Type	Industrial structure characteristics	Transformation characteristics		Key constraints	Examples		
		Before transformation	After transformation		City	Before transformation	After transformation
Growth	With oil, natural gas and other advantageous resource industries as the pillar industries	Deepen the industrial chain around resource-based pillar industries and cultivate new industries in the primary and tertiary industries	Relying on abundant petrochemical and other advantageous resources	Resource efficiency and economic benefits	Songwon	Oil	Oil and gas extraction and chemical industry
Mature	Three pillar industries: petrochemical extraction, steel or mineral primary processing, and forest harvesting	Efficient use of advantageous resources, deep processing of resources, extension of industrial chain to new energy and new materialsetc.	Good economic base, combined with the development and application of high-tech technologies	Technology, talent, capital and innovative spirit	Yanbian Korean Autonomous Prefecture	Coal mining, forestry	Energy and hydropower, forest products processing, clothing and textiles and information electronics
Recession	Coal mining and forest harvesting as the mainstay of the industry	Equipment manufacturing and other industrial systems and green food and other industrial systems	Abandoning traditional industries is difficult and transformation development is slow	Suitable succession industries according to local conditions	Hegang	Coal Mining	Coal industry, graphite industry, green food processing industry, tourism
Regeneration	Traditional resource industries such as petrochemicals and iron and steel are dominant	Multi-industries such as resource deep processing, equipment manufacturing and new materials coexist	Breaking away from resource dependence by improving the level of industrial science and technology innovation	High-tech, science and technology innovation capabilities	Panjin	Petrochemical	Petrochemical and fine chemical industry, oil and gas equipment manufacturing, plastic new materials, marine engineering

On the other hand, these difficulties are related to the characteristics of RBCs. According to the life cycle theory, RBCs have a four-stage development process (growth-maturity-recession, and regeneration). Similarly, RBCs in Northeast China first relied on natural resources such as coal and iron ore to form highly overwhelming energy-consuming industries to stimulate economic development during the formative years. Subsequently, the original pillar industries matured but were impacted by the emerging industries due to their low technology and slow development of successive replacement industries (Yu and Cheng, 2016). Then, during the recession phase, RBCs lose their original resource advantages due to the non-renewal of mineral resources, resulting in the frequent closure of industrial enterprises (Yang et al., 2022). Consequently, the labor force moved out due to fewer job opportunities. Finally, life cycle theory states RBCs in the regeneration stage can eliminate dependency on resources and achieve high-quality economic development and environmental protection benefits. However, for RBCs in Northeast China, most of them are in the maturity and decline stages, therefore, how to get rid of resource dependence and move to the regeneration stage are the main difficulties for RBCs in China at present.

Policy implications

This paper shows the challenges faced by some RBCs in the development by taking Northeast China as an example. Overall, the case of Northeast China reveals the general characteristics of RBC. The leading solution to these problems is to develop replacement industries or improve the competitiveness of resource-based industries (Yu and Cheng, 2016) while building a green development mechanism of resource conservation, industrial optimization, environmental friendliness, and ecological harmony. Therefore, the policy recommendations are given as follows:

1) Promote industrial transformation. RBCs should exploit their comparative and late-mover advantages to cultivate leading industries (Zhang et al., 2021), especially high-tech equipment manufacturing and other new industries with

low environmental pressure and high added value. Table 3 compares the industrial development characteristics of the four types of RBCs and gives the suggested directions for the pillar industries after the transformation of the each type of city. More details are able to be found in the Supplementary Materials.

Subsequently, we propose development suggestions for each type of RBC. The transformation of pillar industries in growing resource cities has abundant resource advantages but is constrained by factors such as low resource utilization efficiency and economic efficiency. Take Songwon City as an example, its original pillar industries are petroleum, oil and gas extraction and chemical industry, respectively. Therefore, the city's transformed pillar industries should be related to petroleum resources, so that the added value of the pillar industries can be increased significantly and its sustainable development capacity can be enhanced.

Mature resource cities inherit a better economic foundation but are constrained by factors such as technology, talent, capital, and lack of innovation. We suggest that the transformed pillar industries should develop toward increasing the added value of resource industries or further expanding different types of industries. Taking Yanbian as an example, we suggest that the city should inherit the traditional advantageous industries such as coal mining and forestry while reforming towards energy and hydropower, forest products processing, garment and textile, and information and electronics industries.

Industrial transformation in recession resource cities is slow and difficult. Besides, it is difficult to find suitable successor industries. In Yichun, for example, we suggest that the city should develop in the direction of broadening the industrial chain based on the development of forestry, and further introduce the "1 + 1″ model to explore forestry-related fields, such as wood processing, forest food processing industry, forest ecotourism, etc.

Regenerative resource cities can gradually get rid of their dependence on resources by improving the level of industrial science and technology innovation, but they are often constrained by the low level of high technology and the general ability of science and technology innovation. Taking Panjin as an example, we suggest that the city, on the basis of inheriting the original petrochemical industry, further develop in the direction of material finishing and actively expand the petrochemical and fine chemical industry, oil and gas equipment manufacturing, plastic new materials, marine engineering, and other related industries. In order to achieve this, talent acquisition (Yu and Cheng, 2016; Yang et al., 2019) is a good way.

2) Consider environmental protection. Considering the severe pressure on ecological environment protection in Northeast China, we think the following three aspects are needed to integrate sustainable development into urban transformation.

The first is to strengthen ecological protection and restoration. For example, the ecological damage and environmental pollution caused by mining should be well evaluated according to the mine ecological planning before mining. The mining scheme should follow the principle of minimizing environmental costs. During the mining process, it is necessary to meet the requirements of the mine ecological environment evaluation index and minimize environmental loss when implementing green mining in the whole process. The mining scheme should always ensure that the reliable implementation of the mine fits ecological environment standards. The predicted loss should compare with the actual loss after mining. As for the ecological damage and the environmental pollution loss caused by mineral resources exploitation, the relevant stakeholders should be compensated following the green property rights system. Meanwhile, the ecological environment of mines should be repaired by their functions and structures to maintain the ecological structure, resistance, self-recovery, and sustainable development ability of the mining areas, and thus guarantee the quality of environmental restoration.

Secondly, strengthen innovations for green mining technology, mainly including water-preserved mining technology, ecological restoration technology of mining wasteland, building and land protection technology, and clean mining technology. Specifically, the government should take the lead in building a technological alliance, extensively appeal to experts and scholars to solve enterprises' problems in production, and improve the technical level with the goal of green and low carbon.

Thirdly, strengthening supervision can promote the intensive and comprehensive utilization of resources and develop a circular economy. Some valuable experiences of cases such as the Ruhr region in Germany can be referred to. Ruhr's government strictly implements environmental regulations on air quality management, pollution source control, and emission treatments. Emission control is realized through national environmental protection legislation, economic policy tools such as subsidies and taxes, and industrial structure adjustment (Hassink and Shin, 2005).

3) Optimize the guiding policies. First, for state-owned assets in the Northeast, there is an urgent need to establish a more optimal and equitable management system, optimize the separation of social and operational functions, and implement the main responsibility for safety management. In this process, using modern management theories, information technologies, and supervision measures can promote the proper operation of the economy of state-owned enterprises under the current laws and regulations. These measures can effectively avoid the loss of state-owned assets in economic transformation and strengthen

the public's awareness of supervision and willingness to participate, thus forming a good atmosphere for economic development.

Secondly, for environmental protection, governments at all levels should strictly implement laws and regulations on environmental protection and strengthen inspection measures while following the basic management principle of "whoever develops, whoever recovers". It is important to encourage private capital to participate in environmental protection, and ecological restoration according to local conditions. In addition, governments should constantly innovate new ecological restoration models and strictly implement environmental protection responsibility.

Thirdly, the governments should actively build a cooperation platform to deepen the exchange between Northeast China and other domestic and foreign regions. It should make full use of location superiority, implement the opening-up strategy, and establish a strategic partnership of sharing resources and achievements. Moreover, the governments should expand the industrial development space and deepen the integrated development of external resource elements and dominant industries.

Fourthly, the local governments should persist in adopting specific policies for each city, enterprise, and mineral to develop and utilize resources by considering the local conditions and thus enhance the resource support capacity. After introducing relevant policies, the government should introduce corresponding supporting measures to help loss-making enterprises out of their current predicament. For enterprises with overcapacity, it is necessary to reduce overproduction. The local government needs to take decisive measures to shut down the enterprises characterized by either inefficiency, high consumption, or low development. At the same time, more attention should be paid to properly handling the exit of zombie enterprises and arranging the transfer of a large number of surplus labor.

Conclusion

This article mainly studies RBCs' problems and their development countermeasures.

1) RBCs in Northeast China have the standard features of global RBCs and the local particularities. More precisely, the common problems refer to economic-related problems, such as the single industrial structure and the low development of substitute industries (Yu and Cheng, 2016). Particularity refers to the environmental issues caused by exploiting natural resources in Northeast China, including industrial pollution, soil erosion (Tan J. et al., 2017), landslides, ground subsidence (Yu and Cheng, 2016).
2) The challenges faced by RBCs in Northeast China are closely related to their development realities and policy systems. Two of the reasons cannot be ignored. On the one hand, the management policies in the Northeast have brought these cities problems of population exodus, environmental damage, and slow economic growth. On the other hand, the characteristics of RBCs lead to a very difficult transformation of the predominantly mature and declining Northeast China.
3) Based on the plight of RBCs in Northeast China, this paper proposes practical policy recommendations from three perspectives: promoting industrial transformation, considering environmental protection and optimizing the guiding policies.

Compared to former studies, we followed the literature such by Heidenreich (2015), Jawadi and Fitti. (2019), Omolade et al. (2019), Nel and Connelly. (2020), John and Tasciotti. (2020), Ogbonna et al. (2020), and Zhang J. et al. (2022) by adopting the method of the case study. However, compared with previous studies, the contribution of this paper is to supplement the solution of how to solve the common and individual issues faced by RBCs. At the same time, compared with the studies of Reid and Gartrell. (2013), and Mitchell and O'Neill. (2016), our contribution derives from analyzing the possible impact of the severe environmental issues faced by RBCs on the follow-up policies and accordingly putting forward targeted measures to guide various RBCs in developing countries, to achieve sustainable development, just like Sunikka (2006), Liu and Gallagher (2010), Omer (2008) and OECD economic surveys European Union 2009, 2009.

Finally, this paper does not explain why both economic transformation and environmental protection in RBCs in China are still in the exploratory stage, but objectively discusses the current development dilemma of RBCs in Northeast China.

Therefore, in future research, it is necessary to discuss how to combine economic transformation and environmental protection (Yang et al., 2019; Zhang et al., 2021), to be able to predict the future trends of RBCs in China from multiple perspectives. In addition to this, we believe that similar to Wei et al. (2022), how to reasonably plan the future resource development of RBCs with an ambitious carbon neutrality target is also a worthy research direction for the future.

Author contributions

YQ led the whole design of the manuscript. WG: editing. GC: Writing-Review. YQ wrote the initial drafts. XN and HW:

revision. All authors reviewed the manuscript and provided comments and feedback.

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The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

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