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Research Article

Rethinking the Low-carbon Transformation of Resource-based Cities Under Net-zero Emission Targets: A Case-study Analysis of Four Resource-based Cities

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Abstract

Objective: Over 120 countries have set or are considering net-zero emissions or neutrality targets. Under the targets, it is necessary to rethink the low-carbon transformation path for resource-based cities, often regarded as incompetent to transition to net-zero directly. Therefore, this paper attempts to summarize the general frame for low-carbon transformation in resource-based cities.

Methods: In this paper, we build a Solow growth model with carbon emission constraints to theoretically analyze the possible path of low-carbon transformation for cities. Then we analyze four typical cities in Japan, Germany, Britain, and America.

Results: The results of theoretical analysis indicate that industrial structure, technological innovation, and clean energy are the key factors for resource-based cities to move towards zero carbon. In addition, the case analysis results show that the authorities of the four cities adopted policies of industry structure adjustment, energy consumption structure adjustment, and urban environment management to achieve the low-carbon transition. The results further validate the conclusions of the theoretical analysis.

Conclusion: Finally, we propose a general framework for resource-based urban transformation. Additionally, we suggest that urban authorities adjust their layout of emerging industries to local conditions, increase investment in low-carbon technologies (especially clean energy), and actively take the lead in environmental governance.

Keywords: low-carbon city, urban transformation, carbon neutrality, case analysis, international experience, theoretical analysis

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1 INTRODUCTION

Addressing climate change has become an important issue of global sustainable development[1]. The Paris Agreement sets out the main requirement for collective action: global anthropogenic carbon emissions need to peak as soon as possible and reach net zero in the second half of this century[2]. A growing number of countries (including their cities) are recognizing their potential contribution to mitigating climate change and have aspired to achieve net-zero. Mobilizing more Commitments is the goal of the "Race to Zero" campaign[3]. As of February 2022, more than 127 countries have announced their intention to achieve net-zero emission targets[4]. Cities generate 60% of the world's economic output and contribute to over 70% of global carbon emissions[5]. Hence, cities play a vital role in achieving the net-zero carbon goal.

Not all cities have the wherewithal and endowments to start the transition to net-zero immediately. Net-zero differs from low-carbon development[6]. Low-carbon transformation in cities is often the first step toward achieving net-zero emission targets. The United Nations Sustainable Development Goal 8 (SDG-8) explicitly calls for progressive improvements in resource use efficiency in global consumption and production to decouple economic growth from environmental degradation. Cities that take mining and processing mineral resources, forests, and other natural resources as the leading industries are called resource-based cities[7]. According to SDG-8, resource-based cities should transition to low-carbon development first. The establishment of net-zero emission targets has brought new challenges and opportunities for transforming resource-based cities[8]. Some cities (like Copenhagen) have successfully made the low-carbon (even almost net-zero emission) transition[9]. However, such a transition is a massive challenge for many resource-based cities due to the high dependence on resources. Resource-based cities must seize the opportunity of low-carbon transformation, peaking carbon emissions as soon as possible. After that, the construction of net-zero cities begins on the road. Therefore, we mainly discuss the low-carbon transformation of resource-based cities under the net-zero goal.

Few literatures have considered the transformation strategies of resource-based cities under the zero-carbon background. In this paper, we build a Solow growth model with carbon emission constraints to analyze the possible path of low-carbon transformation for resource-based cities. We analyze four typical cases of resource-based city transformation in Japan, Germany, Britain, and America to explore the general framework of low-carbon transformation of resource-based cities. The results show that the direction of industrial reconstruction is not to extend the traditional industrial chain but to develop high-tech industry and culture, service industry. Second, with the continuous deepening of urban transformation, the proportion of economic growth driven by traditional carbon-based energy will become smaller and smaller. The replacement of new energy will become mainstream. Third, as public goods, urban environmental governance needs to be led by the government. In the case, the authorities of the four cities adopted policies to restructure the industrial structure, adjust the energy consumption structure and manage the urban environment. After the transformation, the city's industry mainly focuses on the service industry and high-tech industry and realizes the low-carbon and sustainable development of the city.

This study contributes to the literature in several ways. First of all, the successful experience of low-carbon transformation of resource-based cities in the world has not been systematically summarized, especially the lack of detailed case analysis. Second, in this paper, the discussion of resource-based city transformation is not limited to the traditional vision but considers the constraints of carbon emissions. Thirdly, the existing low-carbon transformation of resource-based cities is only a sporadic and tentative practice and has not yet formed a systematic framework for low-carbon urban development.

The rest of the paper is organized as follows. Section 2 combs the literature and points out some possible gaps. Section 3 constructs a Solow model under carbon constraints and analyzes the possible theoretical paths of urban low-carbon transformation. Section 4 examines the theoretical paths with four specific cases. Section 5 discusses the conclusions and policy suggestions.

2 LITERATURE REVIEW

2.1 Resource Curse and Carbon Curse

The essential feature of resource-based cities is the dependence on natural resources, which can bring both a blessing and a curse[10]. On the one hand, rich resource reserve causes rapid development in resource-based cities in processes of industrialization. On the other hand, the resource curse theory states that the countries with large amounts of natural resources tend to grow more slowly than resource-poor countries. Indeed, natural resource dependence results in overspecialization and leads to severe inequality, poverty, and stagnant economic growth[11-13]. Although the resource-based cities become boomtowns apace, Freudenburg[11] stated that the short-run positive impacts would degrade over time, which forces resource-based cities to decrease carbon emissions even more difficultly[8]. These situations prevent resource-based cities from establishing sustainable economies and developing apace.

Under the severe problem of climate change, the carbon curse has been highlighted and researched, which is related to but distinct from the resource curse[14-16]. The carbon curse theory indicates that fossil-fuel-rich areas follow more carbon-intensive developmental pathways than fossil-fuel poor areas[14]. Hence, resource-based cities face severe challenges in embracing low-carbon transformation.

For solution, it is widely believed that financial development plays a positive role in overcoming the carbon curse. Anton and Nucu[17] explained that more significant emission reductions could be achieved via financial development. Generally, financial intermediation drives socioeconomic activities of households and firms via increased access to credit, promotion of trade and investment flows, and enrichment of research and development in technological activities[16]. Considering these economic situations predicted from financial development, the energy substitution habits of households and enterprises in the economy could be varied[18,19].

2.2 Factors Influencing the Transition

Recently, the factors influencing industrial transformation of resource-based cities have been discussed and evaluated. Those studies have stated that the development of those cities is affected by their geographical location, size, and types of natural resources[20]. In addition, the government is a core factor that influences resource-based cities in the issue of resource dependence[21]. On the one hand, incorrect policies or guidelines can oblige resource-based cities to follow the development method of natural resource dependence. For instance, according to Li et al.[22], the fundamental causes of China's resource-based cities' underdevelopment are the country's planned economy, its ineffective tax structure, and its misdirected resource exploitation strategies. Excessive reliance on resources causes resource-based cities' economic systems to become inflexible, forcing them to succumb to the resource curse.

On the other hand, government policies may support the transition of resource-based urban sectors via economic simplicity and diversification, and government policies can decrease or eliminate the negative consequences of resource dependence[21]. Environmental regulation might encourage the industrial development of resource-based cities[23]. Furthermore, some recent studies have discovered that education investment[24], trade structure, tax scheme[25], the volume of foreign direct investment, and political incentives[26]. According to Shao and Yang[27], a shortage of human capital is a significant impediment to resource-based cities' long-term growth.

2.3 Transformation Pathways in Practice

The route of resource-based cities' change has piqued researchers' interest[28-30]. This method may be divided into industrial replacement patterns, industrial chain expansions, and a hybrid of the two. Lorraine (in France), Kitakyushu (in Japan), and Pittsburgh (in the United States) are just a few examples of cities that have used the industrial substitution pattern[21]. Houston (in the United States) has shown a restructuring trend marked by the extension of industry chains. Houston has progressed from a petroleum-based metropolis to a complete technological city by growing its machinery, cement, steel, electricity, transportation, and papermaking businesses[31]. The Ruhr area of Germany expanded its industrial chains and shifted its primary sector from mining to processing. This has modernized the region's economic structure, and its rising sectors have grown tremendously[28].

In addition, according to Liu and Zhuang[32], a systematic compensation mechanism is required to achieve the transition of resource-based cities, and the necessary forms of compensation include boosting fiscal transfers and assisting coal-exhausted cities in developing independently. Environmental regulation and policy compensation are widely acknowledged as essential factors in transforming resource-based cities[33-35]. For example, Japan adopted the Enterprise Rationalization Promotion Law in 1952 in coal towns and the coal industry, which provided three measures for displaced coal miners: 'wider area' resettlement services, vocational training, and financial help for re-employment[36]. As Xing and Luo[37] emphasized, the policies should be targeted at creating an independent economy, driving profitable growth in new industries, and supporting the livelihoods of laid-off miners so that cities can achieve their transformation thoroughly. The cleaner production regulations can drive increasing adoption of renewable sources and promote energy innovation, reducing the negative impact of energy and fossil energy resources on the environment and industrial restructuring on local society and the economy[38]. In France, the French government established departments named DATAR and APEILOR (in succession) to prioritize Lorraine's transition and reduce the impacts on the local population and economy[39].

Low-carbon urban development plays a crucial role in a country's sustainable development, especially for emerging economies such as China[40]. The difference between the low-carbon transformation of resource-based cities and the transformation of traditional industries lies in sustainability, which indicates the high energy efficiency of using low-carbon energy and production technologies[41]. Cities generally seek more sustainable and low-carbon development, and the application of clean energy is a crucial solution to this process[42]. From the perspective of low-carbon technology, Sunikka[43] proposed a path to promote low-carbon city transformation by optimizing industrial structure, improving energy efficiency, and innovating low-carbon technologies. Morrison[44] conducted a comparative study on China, the United States, and South Korea's carbon emission practices and believed that appropriate public funds could be used to develop clean energy and reduce carbon emissions. Through the study of 124 European cities, Croci et al.[45] found that the potential of urban low-carbon transformation is mainly concentrated in the construction and transportation fields. In addition, national policies play an essential role in guiding urban low-carbon development[40]. However, the specific effects of policies on low-carbon development still need to be carefully evaluated[46].

To sum up, a large body of studies has been conducted about the transformation of resource-based cities, which has laid a particular research foundation. However, existing studies still have the following shortcomings. First, the transition path is not combined with the net-zero emission. Second, the low-carbon transition path discussion is primarily practical, lacking economic theory and a general framework. Third, the existing literature is more qualitative review analysis lacking specific and detailed case supplementary explanation. Our work aims to fill these gaps.

3 MATERIALS AND METHODS

3.1 Theoretical Analysis

It is a massive challenge for resource-based cities to promote low-carbon transformation while maintaining rapid economic growth gradually. This paper hopes to explore the low-carbon transformation path of resource-based cities from economic theory by constructing a Solow growth model with carbon emission constraints. Without loss of generality, we assume that the economic production function of A resource-based city meets the form of Cobb-Douglas production function: the final product output is mainly produced by capital $k(t)$, labor $N(t)$, technology and natural resources (carbon emissions here) $R(t)$, and the technological progress is Harrod-neutral. Then there is the production function:

$$Y(t) = K(t)^{\alpha}R(t)^{\beta}[A(t)N(t)]^{1-\alpha-\beta} \quad (1)$$

where the elastic coefficient of capital-output, and the elastic coefficient of labor output, and $\alpha+\beta<1$. The dynamic equations of capital, labor and technological progress are the same as the Solow model[47], which are $\dot{K(t)} = sY(t) - \delta K(t)$, and respectively. A dot over a variable means that this variable is a derivative of time. is the savings rate; is the depreciation rate; is the growth rate of labor; and g is the growth rate of technological progress. Similarly, we assume that $\dot{R}(t) = bR(t)$, where represents the growth rate of carbon emission.

Take the natural logarithm on both sides of Equation (1) at the same time, and we can get:

$$\ln Y(t) = \alpha \ln K(t) + \beta \ln R(t) + (1-\alpha-\beta)[\ln A(t) + \ln N(t)] \quad (2)$$

By deriving the time on both sides of Equation (2), we can get:

$$g_Y(t) = \alpha g_K(t) + \beta g_R(t) + (1-\alpha-\beta)[g_A(t) + g_N(t)] \quad (3)$$

where is the growth rate of variable X. Because $g_A(t)=g$, $g_N(t)=n$, $g_R(t)=b$, Equation (3) can be changed to

$$g_Y(t) = \alpha g_K(t) + \beta b + (1-\alpha-\beta)(n+g) \quad (4)$$

According to a steady-state condition of economic growth in Solow model, if the economy is in a balanced growth path, and must grow at a fixed and equal rate, namely $g_K(t)=g_Y(t)$. Equation (4) turns to

$$g_Y = \frac{(1-\alpha-\beta)(n+g)-\beta b}{1-\alpha} \quad (5)$$

Transposing Equation (5), we can get

$$b = \frac{(1-\alpha)g_Y+(\alpha+\beta-1)(n+g)}{\beta} \quad (6)$$

In achieving the net-zero emission targets, the carbon emission of resource-based cities keeps decreasing, hence, $b<0$. Because $\alpha>0$, $\beta>0$, the carbon emission growth rate is positive or negative depending on the relative size of and $(\alpha+\beta-1)(n+g)$. In order to achieve carbon emission reduction, the possible paths are as follows:

Theoretical path 1: the optimization of industrial structure and the upgrading of traditional industries positively impact urban low-carbon development (corresponding to the relative size of and coefficients in Equation (6).

Theoretical path 2: technological innovation and the improvement of human capital have a positive impact on urban low-carbon development (corresponding to the increase of in Equation (6).

Theoretical path 3: Reducing the proportion of traditional energy in economic growth (g_y) has a positive impact on urban low-carbon development.

3.2 Case Materials

In order to verify the above theoretical analysis and investigate the specific path of resource-based cities in realizing low-carbon transformation, this paper selects four representative cities (Ruhr, Germany; Birmingham, UK; Pittsburgh, USA, and Kyushu, Japan) for case analysis.

3.2.1 Kyushu, Japan

Kyushu, located in the southwest of Japan, is a vital coal-producing area in Japan, with proven coal reserves accounting for nearly 50% of the country's total. Relying on the superior geographical location and rich coal resources, the industry in the Kyushu area developed rapidly. Around the 1920s, the Kyushu area became a heavy and chemical industry base centering on coal, steel, chemical industry, shipbuilding, etc.

3.2.2 Ruhr, Germany

The Ruhr region, located in the western German state of North Rhine-Westphalia, is a world-famous industrial area. From the 19th century to the first half of the 20th century, the coal and steel industry was the core industry of the Ruhr region. Ruhr was once the main production area of coal and iron in Germany. At the same time, it also concentrated machinery manufacturing, chemical industry, and other industries. It is an essential traditional industrial center in Germany.

3.2.3 Birmingham, UK

Located in the middle of England, Birmingham is rich in resources and well-connected to transportation. It is a typical coal city with heavy industry as its central focus. After beginning the British Industrial Revolution, Birmingham found rich coal resources and then developed the metallurgy and machinery manufacturing industry early. The city also expanded rapidly with rapid population accumulation. Birmingham grew into Britain's second-largest city.

3.2.4 Pittsburgh, USA

Pittsburgh, located in southwestern Pennsylvania on the East coast of the United States, is the second-largest city in Pennsylvania. Pittsburgh developed into a typical "coal and iron complex" industrial city due to the rich reserves of bituminous coal, limestone, and iron ore resources in the nearby area and the convenient transportation of inland river ports.

4 RESULTS AND DISCUSSION

4.1 Sensitivity and Scenario Analysis

In this section, numerical examples are used to further verify the propositions mentioned above, and the simulation results of carbon emission reduction scenarios under different parameters are given. On the basis of $0<\alpha<1$, $0<\beta<1$, $0<g_y<0.1$, the specific parameters are set as $g+n=0.06$, the initial value of and is 0.3, and the initial value of is 0.08. The sensitivity analysis results for α, and are shown in Table 1. The results of sensitivity analysis indicate that the optimization of industrial structure and the upgrading of traditional industries positively impact urban low-carbon development. In addition, reducing the proportion of traditional energy in economic growth has a positive impact on urban low-carbon development. Further, we simulate the change of carbon emission rate b under different α, β, g_y values. The results of scenario analysis show that the negative carbon emission rate is concentrated in the space of (seen in Figure 1). These results all show that the key to achieving negative growth in carbon emissions rate is to reduce the proportion of traditional energy use.

4.2 Development Bottleneck of Cases

The Ruhr, Birmingham, Pittsburgh, and Kyushu were once coal-based cities. As the resource-based industry has its industrial cycle, resource-based cities often experience a process from prosperity to decline. In oil replacing coal to become the primary international energy, coal cities' economic level and employment status have been negatively affected, and the urban transformation pressure is enormous.

For example, the Ruhr coal industry began to face a crisis as its coal reserves dwindled, making it more complex and more expensive to extract[48]. Like Germany's Ruhr region, Birmingham has been negatively impacted by structural shifts in energy production and consumption[49]. The price of domestic coal is higher than that of imported coal, leading to the suppression of domestic coal supply. Birmingham's economy began to decline. In the 1950s, Japan established the development strategy of "building a nation through trade." The primary and raw material industries gradually developed the emerging processing industry, and petroleum gradually replaced coal as the primary energy source. The Kyushu region is heading for a recession. Pittsburgh's decline results from its long-term over-reliance on coal and steel, which resulted in severe environmental pollution. Moreover, Pittsburgh also faced many problems, such as high industrial concentration and single employment channels. Its economy fell into a severe recession, making it a famous rust belt city in the United States[50].

4.3 Transformation of Strategy of Cases

4.3.1 Industry Restructuring

In the process of industrial transformation, the above cases did not simply extend the original industrial chain but made full use of their location advantages to reconstruct the industry and realized the diversification and advanced industrial structure by cultivating emerging alternative industries. The heavy and chemical industries represented by coal, steel, chemical, and shipbuilding in the Kyushu area have been transformed into the processing and assembly industries dominated by integrated circuits and automobile products. Kyushu's economy is rejuvenated and has become one of the main bases of Japan's high-tech and emerging industries. Secondly, the Ruhr area introduces information technology, new materials, medicine, and environmental

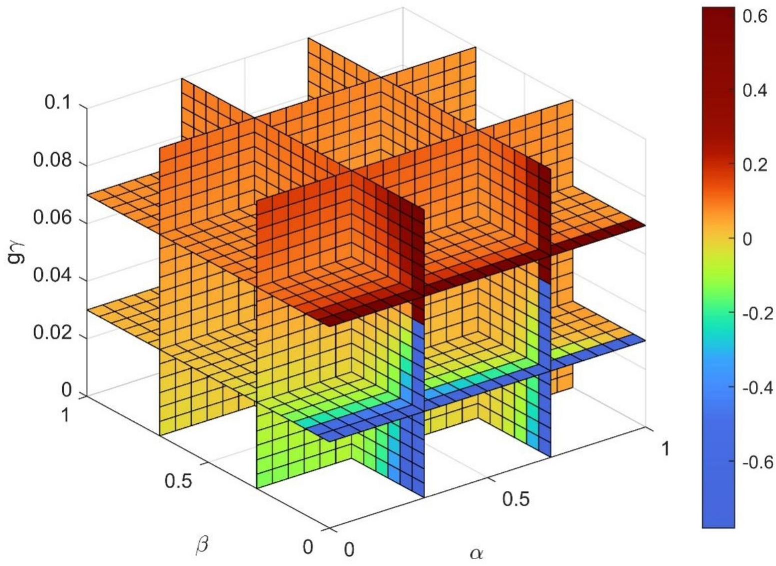

Figure 1. Carbon emission rate simulation under different scenarios.

Table 1. Sensitivity Analysis

Object of Sensitivity Analysis	Variables	Assignment				
a	a	0.1	0.2	0.3	0.4	0.5
	β	0.3	0.3	0.3	0.3	0.3
	g_y	0.08	0.08	0.08	0.08	0.08
	b	0.12	0.113333	0.106667	0.1	0.093333
β	a	0.3	0.3	0.3	0.3	0.3
	β	0.1	0.2	0.3	0.4	0.5
	g_y	0.08	0.08	0.08	0.08	0.08
	b	0.2	0.13	0.106667	0.095	0.088
b	a	0.3	0.3	0.3	0.3	0.3
	β	0.3	0.3	0.3	0.3	0.3
	g	0.05	0.05	0.05	0.05	0.05
	b	0.106667	0.06	0.013333	-0.03333	-0.08

protection[28]. At the same time, 22 institutions of higher learning, including the University of Dortmund, have been built in the region (which is still one of the regions with the highest concentration of universities in Europe) to realize the transformation of emerging technologies into industries through scientific research. Thirdly, Birmingham grasped the location advantage of its proximity to London and determined its orientation and transformation direction as soon as possible. Birmingham boldly eliminated backward traditional industries, created and provided an excellent operating environment for emerging industries, and targeted urban transformation. Finally, Pittsburgh authorities have increased support for services (health care, financial insurance, engineering, etc.) and high-tech industries (robotics, medical devices, etc.). At the same time, the research strength of universities such as the University of Pittsburgh and Carnegie Mellon University has been fully utilized, providing technical support for the development of service and high-tech industries[51]. Theoretical path 1 and part of path 2 are therefore confirmed.

4.3.2 Clean Energy Alternatives

Most traditional resource-based cities face serious problems such as shortage of energy and power supply and environmental pollution. In the process of energy structure adjustment, the above cases replace traditional carbon-based energy with new and clean energy to achieve the goal of energy conservation and emission reduction. For example, Japan's Kyushu closed many coal mining enterprises, invested much money to develop wind, solar and other renewable energy, and promoted energy conservation and consumption reduction through various incentive measures. Ruhr actively develops clean and recyclable coal and natural gas chemical products to reduce carbon emissions and protect the environment. The Ruhr, for example, has built Europe's largest and most advanced solar power plant, the Gelsenkirchen Power Plant. Pittsburgh recognized the importance of clean energy technologies early on and was timely in applying the latest technologies to urban renewal experiments. Pittsburgh has been creative in turning polluted industrial ruins known as "brownfields" into green buildings. Pennsylvania, where Pittsburgh is located, has also aggressively developed its renewable energy industry over the past few decades, taking advantage of its abundant manufacturing workforce and geography to bring in Spanish multinational wind turbine makers Gamesa and Iberdrola. Theoretical path 3 is therefore confirmed.

4.3.3 Urban Environmental Governance

Urban ecological environment regulation is a public product with an external economy, and the government should play a decisive role in environmental regulation. In all these cases, the government directly funded the construction of infrastructure in the declining areas, improved transportation and communication conditions, and controlled environmental pollution to promote the return of talents and labor. Kyushu city, for example, has adopted a government-led system in which civic groups, private companies, universities, and research institutes work together to combat environmental pollution. After decades of ongoing eco-city construction, Kyushu has rapidly recovered its environment and become a famous green eco-city in Japan[52]. Ruhr district set up a chimney automatic alarm system. Each factory has established the recovery of harmful gas and dust devices to control air pollution effectively. Birmingham has improved the dilapidated image of the old industrial city through direct investment in urban infrastructure, control of river pollution, improvement of the urban living environment, construction of the free port, international conference center, and other ways. Pittsburgh has taken on a new look and improved its competitiveness and attractiveness by building office buildings, luxury condominiums, sports venues, convention centers, and renovating old facilities. Theoretical path 2 is therefore confirmed.

4.4 Summary and Enlightenment

Compared with ordinary cities, resource-based cities have their unique characteristics and will inevitably have some obstacles in the process of low-carbon transformation. By comparing the transformation process of resource cities in Germany, Britain, America, and Japan, we find that the resource transformation in the developed countries is mainly influenced by the transformation of energy structure or the adjustment of national industrial structure. The main measures taken by the authorities include restructuring the industrial structure, adjusting the energy consumption structure, and managing the urban environment. The industry after transformation focuses on the service industry and high-tech industry. After completing the transition process, cities can approach or reach economic development in the transition period.

Germany, Britain, America, and Japan have a relatively high market openness. However, in the transformation process of the case city, the government more or less intervenes in the transformation process, rather than relying solely on market-oriented methods. The government has provided much financial support, including continuous subsidies and tax exemptions for resource-based enterprises and alternative industries, investment in urban renewal and construction of industrial parks, etc. The investment of green transformation funds has formed an enormous periodical burden on the local government finance. However, after the successful transformation, the local economy will form specific feedback on local government revenue.

5 CONCLUSION

This paper first reviews the literature related to resource-based city transformation. On this basis, we construct a Solow growth model with carbon emission constraints to analyze the possible path of low-carbon transition for resource-based cities. Finally, four typical cases from Japan, Germany, Britain, and America verify the theoretical approach. More generally, we propose a framework for the low-carbon transformation of resource-based cities under the zero-carbon emission target (Figure 2).

First of all, industrial restructuring is not to extend the traditional industrial chain but to develop the high-tech industry, culture, and service industry. Many resource-based cities still focus on previous resource-based industries in the process of transformation[53]. Secondly, with the continuous deepening of urban transformation, the proportion of economic growth driven by traditional carbon-based energy will become smaller and smaller. The replacement of new energy will become mainstream. The promotion and application of new energy technology are crucial to achieving the goal of zero carbon emission[54]. In recent years, the new energy technology has become more mature with the increasing research and development investment year by year, and its cost will decrease significantly[55]. Finally, the government needs to lead urban living environment governance and ecological restoration projects as public goods, which is crucial to attracting talents and labor. Due to the long time and high-intensity exploitation of resources, resource-based cities generally face severe environmental pollution, ecological destruction, and other problems, which seriously threaten the survival and development of resource-based cities[56].

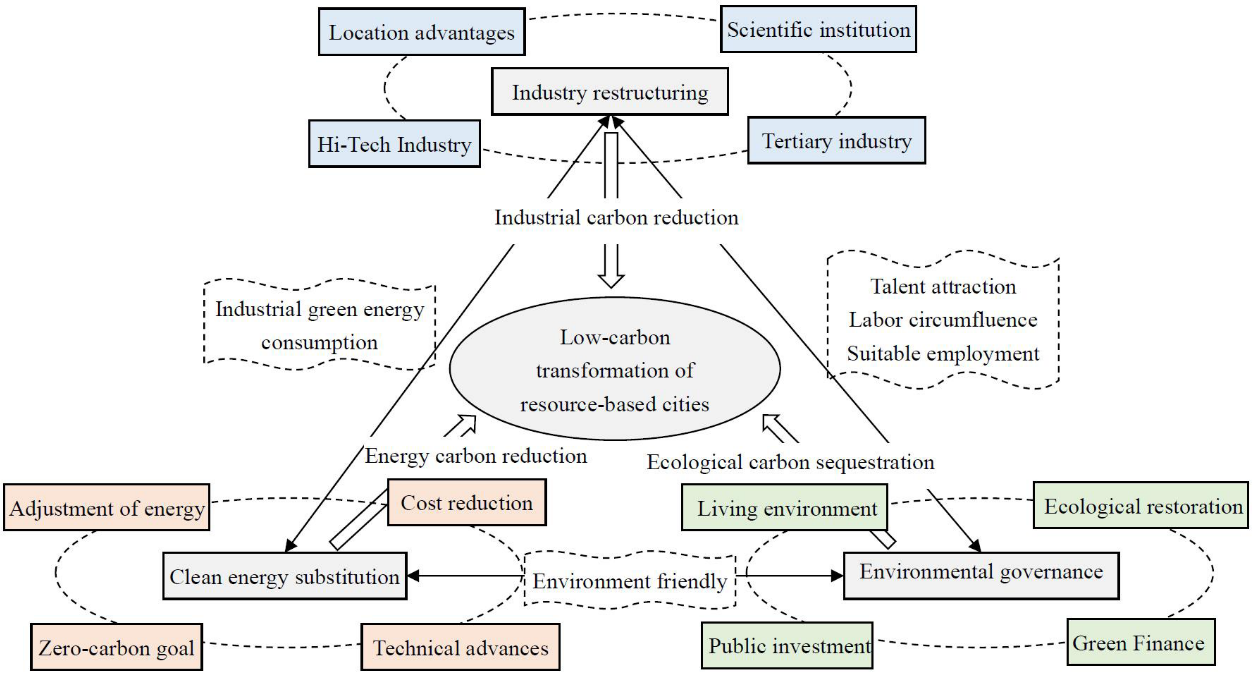

Figure 2. The general framework for the low-carbon transformation of resource-based cities.

Based on the above conclusions, this paper puts forward three policy implications. First, resource-based cities should adopt policies to accelerate the layout of low-carbon emerging industries suitable for local development and transformation. Resource-based cities should evaluate the existing industrial base, formulate the withdrawal schedule of resource-based industries, and prioritize cultivating low-carbon emerging industries through the analysis of industrial competitiveness. Second, the introduction and investment of zero-carbon technologies in key sectors should be strengthened. Achieving the city's net-zero emission targets will require a radical shift in generating, storing, and distributing energy. Therefore, energy investment should be aimed at zero-carbon energy production (especially renewable energy), short - and long-term storage, and modernizing grid infrastructure. Third, the relevant policy system of urban environmental governance and ecological restoration should be improved, and the government should do more in this process. An excellent ecological livable environment contributes to the improvement of carbon sink capacity and effectively attracts talents and the labor force to return. Environmental control projects need many government funds. Under tight government finances, green finance should attract the attention of city managers.

However, this study also has some limitations. Based on previous articles and data, this paper provides a general analysis and framework for transformation but does not classify particular research cities with the various types of natural resources as this study did not conduct field research to gain sufficient data. In addition, due to time and word limitations, this paper does not compare between different countries and political systems, which might allow more examples and details. Nevertheless, notwithstanding these limitations, this study does identify opportunities, challenges, and countermeasures for the transformation of resource-based cities in the given context of carbon neutrality.

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Conflicts of Interest
The authors have no relevant financial or non-financial interests to disclose. The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Author Contribution
Yu Z: Data curation, formal analysis, writing-original draft preparation. Yao X: Software, visualization, writing-review & editing. Bai H: Conceptualization, supervision, project administration. All authors reviewed and approved the final version of the manuscript.

Abbreviation List
SDG-8, The United Nations Sustainable Development Goal 8

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