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Study on the Path of Influencing Factors of Low Carbon Emission under the "Double Carbon" Goal

-- Taking Anhui Province as an Example

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Abstract

China has solemnly announced to the world that it will strive to achieve carbon peak by 2030 and carbon neutrality by 2060. In order to make contributions to promoting carbon peaking and carbon neutrality in Anhui province, this paper takes 16 prefecture-level cities in Anhui Province as research objects, uses qualitative comparative analysis method, and studies multiple concurrent paths and mechanisms of low carbon emissions in the region from four dimensions of economy, population, structure and science and technology based on the perspective of configuration. Four urban low-carbon transformation paths of stable development and green production, economic solid industry, industrial clean development and industrial service transformation were summarized, and the gray correlation degree between industrial structure and carbon emissions of old industrial cities in Anhui province was calculated to explore the influence degree of industrial structure on the configuration path.

Keywords

Low-carbon; Industrial Structure; fsQCA; Grey Correlation.

1. Introduction

After two years of preparation and 13 days of arduous negotiations, the 26th session of the Conference of the Parties to the United Nations Framework Convention on Climate Change, which ended on 13 November 2021, reached the first international agreement to phase down the use of coal, completed the implementation rules of the Paris Agreement, and made positive progress. As a contributor to global climate governance and a leader in the construction of ecological civilization in the world, China has actively implemented its actions since its accession to the Paris Agreement, and has successively announced the vision of achieving peak carbon neutrality (" dual-carbon "). It has formulated and updated its Intended Nationally Determined Contributions (NDCS) and published the White paper on China's Policies and Actions to Address Climate Change, thus taking concrete actions to control the rise in global temperature. Realizing the "dual carbon" goal is a broad and profound economic and social systemic change. China's updated NDCS raise the carbon intensity target of the NDC to more than 65%, and also provide clear guidance for the 14th Five-Year Plan to accelerate the pace of high-quality development and low-carbon transition. The 20th Congress once again emphasized that we should base on China's energy and resource endowments, adhere to the principle of standing before breaking, and implement carbon peak-peak action in planned steps. It is expected that through the strategic control of the development path, the innovation of long-term decarbonization development path will be gradually realized. In this context, Anhui, as a province with large coal resources endowment in the east of Central China, has become the most heavily affected[1] area of carbon emission due to the "low efficiency and high energy" of energy utilization. As an important old industrial base and a province with large mineral

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resources, urban resource-based cities play an important role in the economic and social development of Anhui province. In 2020, the Provincial Development and Reform Commission issued the "Implementation Opinions of the CPC Anhui Provincial Committee and the People's Government of Anhui Province on Fully, Accurately and Comprehensively Implementing the New Development Concepts and Doing a good Job in Achieving carbon Peak carbon Neutrality", which clarified the goals, paths and tasks of achieving carbon peak carbon neutrality in our province. The realization of urban low-carbon development is the leading direction of future urban development, urban low-carbon development involves economy, society, population, resources, environment and other fields[2], is a complex system engineering, in the large-scale transformation at the same time should also pay attention to the scientific strategy, otherwise it will affect the long-term development of the city, bring irreparable losses[3]. Driven by the goal of "double carbon", research on the configuration path affecting low-carbon emissions, and put forward suggestions for the adjustment of low-carbon urban transformation in Anhui province, coordinate the promotion of energy conservation and emission reduction, industrial transformation and ecological protection, strive to improve the green content of economic development, and make contributions to the realization of the target of carbon peak and carbon neutrality on schedule.

2. Research Status of Influencing Factors of Carbon Emission at Home and Abroad

The world attaches great importance to the issue of carbon emission. In 2003, the British government published a white paper on energy, "Our Future Energy: Creating a Low Carbon Economy", and the concept of "low carbon economy" was first mentioned[6]. According to the statistics of the Energy & Climate Intelligence Unit(Energy and Climate Information Group), 135 countries and 11 regions have put forward the "zero carbon" climate goal so far, following the "net zero carbon" principle, covering 88% of the world's carbon emission areas and 85% of the population. Which is in line with China's "carbon neutrality" goal. The implementation of the Tokyo Carbon cap-and-Trade Program in Japan marks an important milestone in the development of a low-carbon city in Japan, aiming to reduce Tokyo's greenhouse gas emissions[7] by 25% by 2020 compared to 2000 levels. South Korea has introduced an emissions trading system and enacted the Low Carbon Green Growth Basic Law, which sets a target of a 30% relative reduction in greenhouse gas emissions by 2020. On July 14, 2021, the "Fit for 55" plan was adopted in the European Union, providing a package of initiatives to combat climate change to achieve a 55% reduction in carbon emissions by 2030 compared to 1990 levels and carbon neutrality[8] by 2050. The research methods of foreign scholars on the driving factors of carbon emissions mainly include structural decomposition analysis (SDA) and index decomposition analysis (IDA). SDA is mainly analyzed by establishing input-output model, as detailed in Su & Ang[11][9] and Nagashima[10]'s research. However, Zhou & Ang's research also pointed out that it is limited to additive decomposition, and complex input-output is not easy to be established. Ang & Liu[12]'s research explained the advantages of IDA method, which mainly includes two forms[13]: arithmetic average index decomposition (AMDI) and logarithmic average index decomposition (LMDI). The latter has advantages in theoretical basis, applicability, flexibility and easy analysis of results, and so on, which is favored[14-15] by many scholars.

Most domestic research perspectives on carbon emissions focus on countries, key industries and typical enterprises, and study national macro policies such as carbon tax[16], carbon emission rights market[17] and environmental regulations[18]. And the impact of industrial transformation[19], technological progress[20], energy structure adjustment[21] and energy endowment[22] on carbon emissions. Research on the factors affecting carbon emissions or

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carbon productivity. The key factors that have been identified mainly include economic growth, industrial structure, opening-up, energy consumption structure and technological innovation. Tang Zhipeng et al. (2017) believe that industrial structure, energy structure, technological progress and labor productivity are the main factors affecting carbon productivity, in which energy structure has a negative impact on carbon productivity, while industrial structure (the proportion of service industry), technological progress and labor productivity have a positive impact[23] on carbon productivity. Lin Xueqin et al. (2021) believe that productivity level, opening to the outside world, industrial R&D input, energy consumption intensity, energy consumption structure and heavy industry level are the main factors affecting carbon emissions, and the first three factors will promote carbon emission efficiency[24].

From the macro level of productivity distribution, the impacts of the primary, secondary and tertiary industries on carbon emissions are studied. From a nationwide perspective, Zhong Weizhou et al. (2015) found that the contribution rate of the secondary industry to the carbon emission of the whole society is relatively[25] large. Li Hong et al. (2016) constructed the STIRPAT model and analyzed the emission reduction strategies of provinces and cities across the country, and found that the proportion of the secondary industry in carbon emissions of some provinces and cities was significantly positively correlated[26]. From the perspective of various regions, except for the Yangtze River Economic Belt[27], Qinghai and Xinjiang[28], the tertiary industry has the highest correlation with carbon emissions, and the Pearl River Delta cities[29], Hebei[30] Province[31], and six central provinces including Henan, Shanxi, Hubei, Anhui, Hunan and Jiangxi[32], Liaoning[33], Shaanxi and Gansu[28] provinces all have the greatest impact on carbon emissions from the secondary industry compared with the primary and tertiary industries. It can be seen that regional differences will affect the correlation degree of different industries on carbon emissions, and industrial structure is also an important factor affecting the low-carbon path. Based on the perspective of configuration, from the dimensions of economy, population, structure and scientific and technological level, this paper uses qualitative comparative analysis method (QCA) to study the path affecting carbon emissions by taking Anhui Province as an example, and is committed to further accelerating high-quality economic development, building a new development pattern with domestic great cycle as the main body and domestic and international double cycles promoting each other, and accelerating the construction of a better Anhui.

3. Variable Selection and Model Construction

3.1. Result Variable Calculation Method

In this paper, the method of Li Jian et al. (2012) is used for the calculation of carbon emissions. The calculation formula is as follows:

$$C_i = \sum_j E_{ij} \times S_j \times F_j \tag{1}$$

Where is the total carbon emission of region i, is the consumption of Class j fossil energy in region i, is the emission coefficient of Class j fossil energy to standard coal, is the carbon emission coefficient of Class j fossil energy. C_i E_{ij} S_j F_j In this paper, the average value of carbon emission coefficient is adopted for computational science.

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Table 1. Conversion coefficient of fossil energy to standard coal1

Unit: Kg standard coal /kg raw coal

Source of data	Raw Coal	Crude oil	Natural gas
China Energy Statistical Yearbook	0.7143	1.4286	1.33

Table 2. carbon emission coefficient of fossil energy2

Unit: Kg carbon /kg standard coal

Source of data	coal	oil	Natural gas
U.S. Department of Energy/Energy Information Administration	0.702	0.478	0.389
Japan Institute of Energy Economics	0.756	0.586	0.449
Energy Research Institute, National Development and Reform Commission	0.7476	0.5825	0.4435
Mean	0.7352	0.5488	0.4272

Table 3. Urban carbon emissions in Anhui Province, 2015-20203

Unit: billion tons

Districts	2015	2016	2017	2018	2019	2020
Hefei City	0.1715	0.1601	0.1663	0.1783	0.1902	0.2039
Huaibei City	0.0480	0.0434	0.0477	0.0497	0.0491	0.0529
Bozhou City	0.0359	0.0307	0.0318	0.0333	0.0385	0.0437
Suzhou City	0.0540	0.0501	0.0511	0.0542	0.0563	0.0615
Bengbu	0.0484	0.0416	0.0433	0.0451	0.0453	0.0494
Fuyang City	0.0976	0.0713	0.0754	0.0788	0.1021	0.1195
Huainan City	0.0492	0.0548	0.0536	0.0531	0.0658	0.0870
Chuzhou	0.0749	0.0507	0.0536	0.0564	0.0762	0.0913
Lu 'an City	0.0431	0.0400	0.0384	0.0425	0.0525	0.0665
Ma 'anshan City	0.1170	0.1419	0.1504	0.1588	0.1492	0.1620
Wuhu City	0.0833	0.0897	0.0893	0.0918	0.0874	0.0994
Xuancheng	0.0474	0.0443	0.0463	0.0500	0.0522	0.0585
Tongling City	0.0397	0.0536	0.0585	0.0618	0.0501	0.0495
Chizhou	0.0387	0.0353	0.0359	0.0398	0.0420	0.0500
Anqing	0.0619	0.0580	0.0663	0.0706	0.0744	0.0795
Huangshan	0.0145	0.0138	0.0140	0.0153	0.0164	0.0178

The calculated trend of carbon emissions in Anhui Province from 2015 to 2020 shows that carbon emissions in most cities have gradually increased since 2018 after a short decline, which is necessary to consolidate the current low-carbon measures and form a "combination" of effective low-carbon policies.

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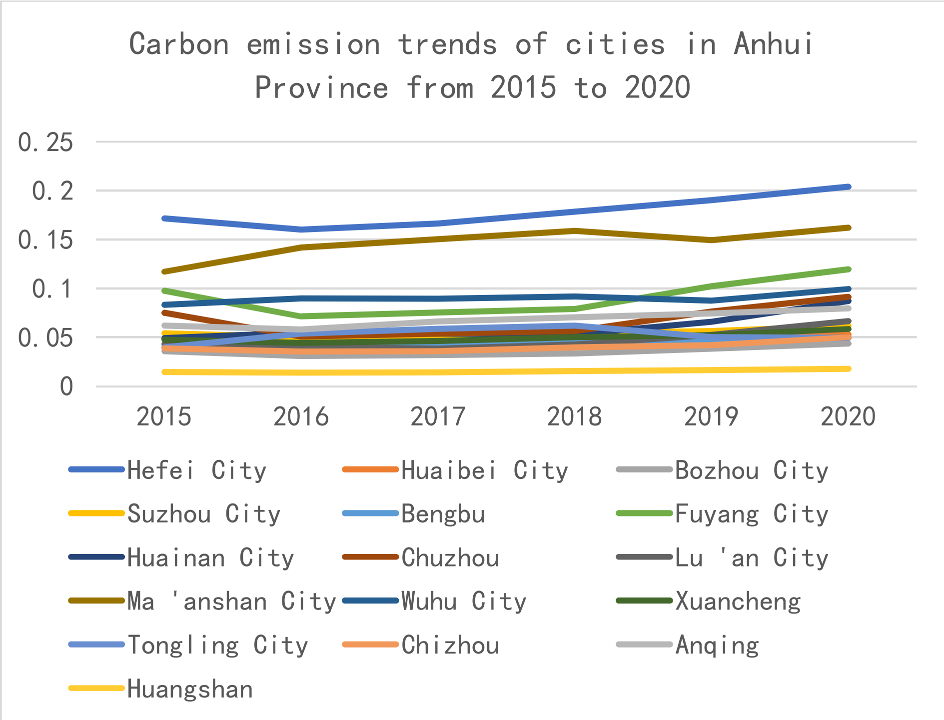

Figure 1. Carbon emission trend of each city in Anhui Province1

3.2. Conditional Variables

Based on the research index proposed by Huang Xiulian (2022), this paper comprehensively considers economic, population, structure and scientific and technological factors. Economic factors are represented by per capita GDP, population factors are represented by urbanization rate, and industrial structure is represented by the ratio of output value of the primary industry to GDP, the ratio of output value of the secondary industry to GDP and the ratio of output value of the tertiary industry to GDP. The carbon emission of the three industries is investigated. The number of patents applied by enterprises reflects the utilization efficiency of input resources. In view of the objective fact[36] that the distortive incentive effect of the enterprise's invention patent activities is relatively small, and the technical content is the highest[37], which may better reflect the enterprise's independent innovation ability. Therefore, the number of authorized invention patent applications is taken as a scientific and technological index to reflect the level of technology. In this paper, the variable data of 2020 are selected from China Energy Statistical Yearbook, Anhui Provincial Statistical Yearbook, National Bureau of Statistics, etc.

Table 4. Variables and definitions4

Variables		Index name	Definition
Result variable		Carbon footprint (CE)	Carbon emissions from fossil energy consumption
Conditional variables	Economic factors	GDP per capita (AGDP)	GDP/ total population
	Demographic factors	Urbanization rate (UR)	Urban population/total population
	Industrial structure factors	Proportion of primary industry (PI)	Output value of primary industry /GDP
		Share of secondary industry (SI)	Output value of secondary industry /GDP
		Share of tertiary industry (TI)	Output value of the tertiary industry /GDP
	Science and technology factors	Invention patents (IP)	Number of authorized invention patent applications

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3.3. Model Construction

Six indicators were extracted from the four dimensions of economy, population, structure and science and technology to explore the influencing factors of low carbon emission in Anhui province and summarize the path of low carbon in cities. Compared with regression analysis, fsQCA's discussion on the relationship between variables is more universal. In addition, fsQCA method can also explain the linkage relationship between different anthems, and more clearly show the interaction relationship between variables and the causal relationship between the anthems configuration and the outcome variables. Therefore, based on configuration thinking, this paper uses fsQCA method to build a low-carbon driving mechanism model according to condition variables and outcome variables, as shown in Figure 22.

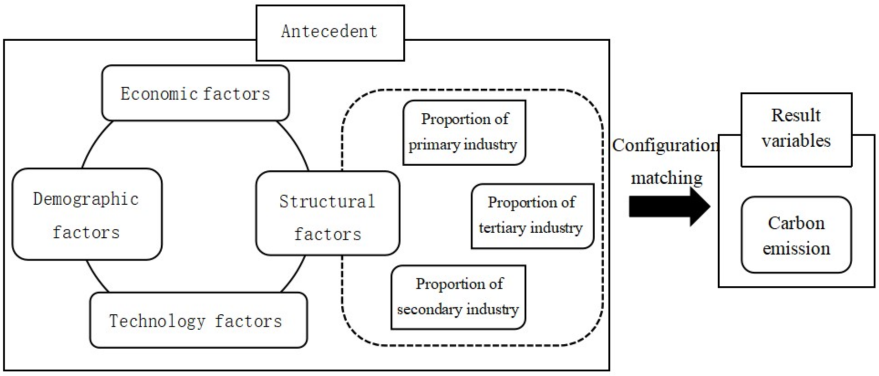

Figure 2. Model of low-carbon driving mechanism3

4. Research Design

4.1. Data Calibration

Combined with the literature and the actual meaning[38] of variables, this paper adopts the direct calibration method to convert the data into membership scores[39] of fuzzy sets. The specific operation is to set the calibration points of variables (full membership, crossing point and no membership at all) as the upper quartile, median and lower quartile of descriptive statistics of case samples respectively.

Table 5. Calibration of variables

	Results and Conditions	Calibrating anchor points		
		Completely unattached Membership =0.25	Crosspoint Membership =0.5	Full membership = Membership =0.75
Result variable	Carbon footprint	0.049861038	0.06396725	0.093330148
Conditional variable	GDP per capita	42690.89545	63526.43996	76147.80463
	Urbanization rate	0.534325	0.6025	0.646625
	Proportion of primary industry	0.041202173	0.059722668	0.078829103
	Proportion of secondary industry	0.378920574	0.419625687	0.477266765
	Proportion of tertiary industry	0.486355692	0.508210135	0.518158978
	Invention patents	444.75	826	1359.25

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4.2. Necessity Analysis

According to the existing literature, the consistency judgment criteria of QCA essential conditions are relatively uniform, and most of them adopt a higher threshold value of 0.9. Table 6 shows the test results of necessary conditions for high carbon emission and low carbon emission analyzed by fsQCA 3.0 software. It can be seen that the consistency level of all conditions is less than 0.9, indicating that the necessity of each single condition is at a low level, indicating that there is no single necessary condition for promoting carbon emission among the anthems of carbon emission.

Table 6. analysis of necessary conditions for variables

Conditional Variables	Result variable			
	High carbon emissions		Low carbon emissions	
	Consistency	Coverage	Consistency	Coverage
GDP per capita	0.602484	0.620205	0.474214	0.482097
~ GDP per capita	0.496894	0.488998	0.626415	0.608802
Urbanization rate	0.613665	0.629299	0.452830	0.458599
~ Urbanization rate	0.472050	0.466258	0.633962	0.618405
Proportion of primary industry	0.474534	0.496749	0.581132	0.600780
~ Proportion of primary industry	0.618634	0.599278	0.513208	0.490975
Proportion of secondary industry	0.572671	0.578419	0.498113	0.496863
~ Proportion of secondary industry	0.501863	0.503113	0.577359	0.571607
Proportion of tertiary industry	0.481988	0.489281	0.623899	0.625473
~ Proportion of tertiary industry	0.631056	0.629492	0.490566	0.483271
Invention patents	0.801242	0.838752	0.316981	0.327698
~ Invention patent	0.357764	0.346570	0.844025	0.807461

4.3. Analysis of Results

Since the number of cases in this paper is 16, which belongs to the medium sample in QCA analysis, the threshold of case frequency is set to 1, and the original consistency threshold is set to 0.8 for reference to previous studies. By comparing the nested relationship between the intermediate solution and the reduced solution, if the antecedent condition appears in both the reduced solution and the intermediate solution, it is the core condition and has an important impact on the result. If the condition only appears in the middle solution, it is the edge condition, which plays an auxiliary role[38]. The configuration results of carbon emission paths are shown in Table 7. Among them, there are four low-carbon emission paths (S1a, S1b, S2a, S2b), among which S1a, S1b and S2a, S2b respectively constitute second-order equivalent configurations with the same core conditions (Fiss, 2011). According to the combination characteristics of conditions and the heterogeneity of urban resource endowments, the following four pathways can be summarized.

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Table 7. Results of carbon emission path configuration

	Low carbon emission				High carbon emissions			
	S1a	S1b	S2a	S2b	NS1	NS2	NS3	NS4
GDP per capita (AGDP)		●		●		●	●	
Urbanization rate (UR)			●			●	●	●
Proportion of primary industry (PI)	●	●			●			●
Proportion of secondary industry (SI)		●	●			●		
Tertiary sector share (TI)			●	●			●	●
Invention patent (IP)					●	●	●	
Typical sample	Bengbu	Chizhou	Tongling and Huaibei	Huangshan	Fuyang	Ma 'anshan, Wuhu and Chuzhou	Hefei	Huainan
Raw coverage	0.193711	0.198742	0.207547	0.100629	0.18882	0.356522	0.149068	0.104348
Unique coverage	0.100629	0.109434	0.168554	0.064151	0.15528	0.31677	0.118012	0.0795031
Concordance rate	0.974684	0.88764	0.896739	0.987654	0.962025	0.940984	0.991736	0.831683
Coverage of the solution	0.54717				0.713043			
Agreement rate of the solution	0.91579				0.937908			

Note: ● indicates a conditional value of 1 (occurring/strong/high level), and ⓧ indicates a conditional value of 0 (not occurring/weak/low level). A large ● or ⓧ represents the core condition, which can completely form the path of a reduced solution; A small ● or ⓧ indicates the peripheral conditions. White space indicates "irrelevant" cases, where a value of 0 or 1 (strong or weak) has no effect on the result.

Path 1: Steady development and green production low-carbon path. Path S1a points out that low urbanization rate and low invention patent level are the core conditions, and complementary paths with low per capita GDP, high proportion of primary industry, low proportion of secondary industry and low proportion of tertiary industry are the marginal conditions to reduce carbon emissions. S1a indicates that population and scientific and technological level constitute the sufficient combination of conditions for the low-carbon path. Under the stable level of economic development, low urbanization rate and scientific and technological level, and the increasing proportion of the secondary industry and the tertiary

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industry restrain low-carbon emission, indicating that the current degree of industrial greening is not high, and it is necessary to accelerate the process of industrial greening and green industrialization. The current development of the primary industry does not affect the low-carbon transformation of the city. The movement of population into cities will increase carbon emissions, indicating that the current labor force is mostly flowing to industries with high carbon emissions, or there are more labor-intensive industries with high carbon emissions. It is necessary to replace labor in high-carbon industries, improve labor quality and reduce the number of workers. The typical case city of this route is Bengbu City, take it as an example. According to relevant statistics, Bengbu mainly takes the processing and manufacturing industry as the leading industry. Therefore, it is beneficial to energy conservation and emission reduction to reduce the carbon emission of the secondary industry as the main and the tertiary industry as the supplement. The development of Bengbu takes innovation development and green manufacturing as the main line, develops thin-film solar energy industry, controls daily industrial energy consumption, and promotes the construction of photoelectric buildings, so as to achieve the goal of controlling climate change. In particular, consolidate the development of silicon-based and bio-based industries with output value of "double hundred billion", optimize the scale of energy utilization, mainly represented by distributed energy and polylactic acid products, and support the replacement and transformation of fossil energy.

Path 2: to promote the path of economic solid industry low-carbon. Path S1b points out that low urbanization rate and low invention patent level are the core conditions, and complementary paths with high per capita GDP, high proportion of primary industry, high proportion of secondary industry and low proportion of tertiary industry are the marginal conditions can reduce carbon emissions. When this path achieves the decoupling of low-carbon emission from economic growth, and the urbanization rate representing population mobility is low, the stable development of the primary and secondary industries does not affect the realization of the low-carbon goal, indicating that the green transformation and upgrading of the primary and secondary industries have remarkable effects, and a certain degree of energy consumption will promote low-carbon emission and weaken the status of science and technology. However, the proportion of high-level tertiary industry will increase carbon emissions, which shows that the degree of green development of tertiary industry is not high enough, and there is still room for further green improvement. The typical city to achieve low carbon emission under this path is Chizhou City, taking Chizhou City as an example. Chizhou City provides a reference for the transformation and development of resource-based industries into manufacturing industries, and the transformation of the development mode of cluster industries promotes the industry to enter a new stage of high-quality development. In particular, at the same time of industrial development, it has realized the transformation of traditional manufacturing industry to high-tech industry, and has become one of the first national low-carbon city pilots officially approved by the National Development and Reform Commission, which is also the first low-carbon pilot city in Anhui province, and its research results are leading in Anhui province. This is mainly attributed to Chizhou city has been adhering to the policy of ecological city, improve the main function positioning, targeted to formulate medium and long-term low-carbon development planning, the development of greenhouse gas inventory to refine its low-carbon emissions regulatory measures, but also set up a set of low-carbon tourism "Chizhou index", the basic formation of its low-carbon industrial system, the need to stabilize the current industrial structure sustainable development.

Path 3: Low-carbon path of clean development of industry. Path S2a points out that the path with low proportion of primary industry and low invention patents as the core conditions, and the path with complementary high urbanization rate, high proportion of secondary industry and high proportion of tertiary industry as the marginal conditions can reduce carbon emissions. Economic factors have almost no influence, and the core driving role is played by

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focusing on the high-quality development of the industry. Under this path, the low level of science and technology is difficult to play a role in the short term. To reduce carbon emissions, it is necessary to increase the urbanization rate to a certain extent, and vigorously improve the low-carbon level of the production of the secondary industry and the tertiary industry, so as to achieve the goal of reducing carbon emissions. Tongling City, for example, belongs to the resource-based old industrial city, based on resource endowment and industrial foundation, strive to pick the "crown pearl" of the copper industry, accelerate the transformation of old and new momentum, and build a national industrial transformation and upgrading demonstration zone. Under the governance framework of the "four systems" of system, technology, market and supervision, Tongling City takes the industry-strong city as the leading strategy, and gradually promotes the trend of intelligent, service-oriented, green and high-end development of the industry, taking the free ride of the integrated development of the Yangtze River Delta. Strengthen the construction of industrial clusters such as the new generation of information industry, strengthen the development of key industrial chains, implement the "chain length system" of industrial chains, and further promote industrial agglomeration. While developing industries, we should embrace "waste free" in all aspects, and explore new ways to reduce, recycle and make sound solid waste harmless in low-carbon emission reduction.

Path 4: Low-carbon path of industrial service transformation, path S2b points out that low proportion of the primary industry and low invention patents are also the core conditions, and complementary high per capita GDP, low urbanization rate, low proportion of the secondary industry and high proportion of the tertiary industry as the edge conditions of the path can reduce carbon emissions. S2b indicates that the per capita economic growth and the increase in the proportion of the tertiary industry will be conducive to the low-carbon emission of the city. Due to the low level of science and technology and the lack of innovation ability, it is difficult to reduce carbon emissions through scientific and technological factors in the short term. The only way to reduce carbon emissions is to reduce the proportion of the secondary industry or improve the current green development degree of the secondary industry, develop the tertiary industry more and upgrade the industrial level. A typical city is Huangshan City. Taking Huangshan City as an example, it is a tourism-oriented city, and Huangshan Scenic Area is listed as the national low-carbon tourism demonstration zone. While the growth rate of main economic indicators is among the best in economic development, a series of measures also promote the agglomeration of high-end modern service industries, making Huangshan a national tourism demonstration zone. It is speeding up the green transformation of the secondary industry, developing emerging industries, extending the industrial chain and building core competitiveness. In the past decade, China has made great efforts to build a resource-saving and environment-friendly industrial system, and set up a mechanism for realizing the value of ecological products from traditional tourism to secondary and tertiary industries, with a deep grasp of the idea that clear waters and lush mountains are gold and silver mountains, and carbon peak carbon neutral actions are at the forefront.

4.4. Robustness Test

To increase the credibility of the conclusion, conduct a robustness test. According to the hypothesis of causality asymmetry, the anthems of the results of high level and low level should be different. Taking "high carbon emission" as the result variable, the output paths NS1, NS2, NS3 and NS4 (see Table 7) are different from the original configuration, and there is no case of the same overall condition or core condition, which proves that the original configuration is reliable. Secondly, the PRI consistency is increased from 0.70 to 0.75, and the resulting configurations are basically the same. The robustness test shows that the results are robust.

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5. Further Discussion

5.1. The Influence of Old Industrial Cities in Anhui Province on the Low-carbon Path

Since 2005, Anhui Province has been steadily in the emission reduction observation area[41]. The coal-based energy consumption structure of Anhui manufacturing industry has obvious characteristics, and the use of large amounts of coal leads to the rapid increase[42] of carbon emissions. The above four low-carbon paths all involve the promotion effect of three industrial development on the low-carbon development path, but the emphasis of industrial development is different. The difference between S1a and S1b, which have the same core conditions, mainly lies in the influence of the two index variables of per capita GDP and the proportion of secondary industry. The lower per capita GDP level and the proportion of the secondary industry in the S1a path will promote low-carbon emissions, while the increase of per capita GDP level and the increase of the proportion of the secondary industry in the S1b path will promote low-carbon emissions. The difference between S2a and S2b with the same core conditions mainly lies in per capita GDP, urbanization rate and the proportion of secondary industry. The difference is that the proportion of secondary industry in S2a path is higher, while the proportion of secondary industry in S2b path is lower. Previous studies[24-32] have suggested that the secondary industry with high energy consumption has the greatest impact on carbon emissions. This paper will further study the interactive relationship between industrial structure and carbon emission.

As an important old industrial base and a province with large mineral resources, the old urban industrial zone and resource-based city play an important role in the economic and social development of the province. From the perspective of the province, differentiated management should be implemented for regions with different carbon emission intensity, and the problem cannot be solved "one-size-fits-all". Since the "National Old Industrial Base Adjustment and Transformation Plan (2013-2022)" was promulgated and implemented, Anhui Province included in the plan Huaibei, Bengbu, Huainan, Wuhu, Ma 'anshan, Anqing City and Hefei Yaohai District six cities and one district and provincial relevant departments attach great importance to, actively implement the main responsibility, and have achieved remarkable results. In recent years, the level of urbanization has exceeded the national average speed, and the province has begun to enter the city-led society, and strives to basically complete the task of relocation and transformation of the old industrial areas in the urban areas of the province before 2022. Basic industries are the basis of emerging industries, and the problems of energy consumption and carbon emissions are inevitable in the development of resource-endowed basic industries. In order to explore the typical characteristics of low-carbon transformation of Anhui Province's cities and test the effectiveness of transformation, and calculate the correlation degree of industrial structure of old industrial cities, a gray correlation analysis model based on the gray system theory developed by Professor Deng Julong[43] is adopted. To analyze the broad gray correlation degree between carbon emission and industrial structure of old industrial cities. Grey correlation analysis is actually the geometric proximity between the analysis series in the spatial position, which is suitable for the study of small sample, imperfect data and uncertain parameters. Its dimensionless process converts the atypical distribution into a regular[44] distribution. If the degree of synchronous change of the change trend of the two sequences is higher, that is, the more similar the change curve is, the higher the correlation degree between the two sequences is, and vice versa, the lower it is.

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5.2. Measurement of Correlation Degree between Industrial Structure and Carbon Emission in Old Industrial Cities of Anhui Province

In this paper, the time series of carbon emissions is taken as the system characteristic master series X0, and the proportion of the first, second and third industries in six old industrial cities in Anhui province, namely the rationalization index of industrial structure and the industrial structure upgrading index of the ratio of the tertiary industry to the secondary industry, represents the industrial structure and takes its time series as the comparison factor series Xi. Among them, the proportion of the first, second and third industries is expressed by X21, X3 and X respectively, and the advanced index of industrial structure is expressed by X4.

Then, where n represents time, i=0,1,2,3,4. $X_i = \{x_i(1), x_i(2), \ldots, x_i(n)\}$.

The correlation degree between carbon emission and industrial structure index was calculated and its magnitude was sorted. In other words, the more similar Xi0 and X series are, the greater the grey correlation degree is, and the smaller it is on the contrary. The specific calculation steps are as follows:

5.2.1. Data Standardization

This paper uses the method of initial value to standardize the data, that is:

$$X_i = \left\{ \frac{X_i(1)}{X_i(1)}, \frac{X_i(2)}{X_i(1)}, \ldots, \frac{X_i(n)}{X_i(1)} \right\} \tag{2}$$

5.2.2. Calculate the Correlation Coefficient ζ

The formula is:

$$\zeta(k) = \frac{\min_i \min_k |x_0(k) - x_i(k)| + \rho \max_i \max_k |x_0(k) - x_i(k)|}{|x_0(k) - x_i(k)| + \rho \max_i \max_k |x_0(k) - x_i(k)|} \tag{3}$$

$|x_0(k) - x_i(k)|$ $\min_i \min_k |x_0(k) - x_i(k)|$, the smallest difference in Xn, and then find the smallest difference from all the n comparison curves. $\max_i \max_k |x_0(k) - x_i(k)|$ Is to find the greatest difference in each of the above comparison curves, and find the greatest difference in all the comparison curves. ρ It is called the resolution coefficient, and the value is between 0 and 1, with 0.5 as the reference of Li Jian et al. (2012).

5.2.3. Calculate the Correlation γ_{ni}

$$\gamma_{ni} = \frac{1}{n} \sum_{k=1}^{n} \zeta_{ni}(k) \tag{4}$$

According to the calculation, the conclusion in Table 8 is drawn, which can be seen:

(1) From the perspective of the proportion of the three industries, the correlation degree between carbon emissions and industrial structure related indicators of the six old industrial cities in Anhui Province is greater than 0.5, indicating that industrial development is related to carbon emissions; (2) According to the calculation results, there are more cities in which the development of the tertiary industry, mainly the service industry, has the greatest correlation degree to carbon emissions. There are five cities in which the correlation order of carbon emissions is the third, second and first industries, realizing the "three two one" industrial structure. The overall industrial rationalization degree is high, and the industrial structure

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adjustment effect of the old industrial cities in Anhui Province is remarkable; (3) The industrial correlation degree of Huaibei city for carbon emissions is the first, third and second industries, and the primary industry has a higher correlation degree for carbon emissions. Therefore, the low-carbon path of industrial clean development can be adopted to develop the second and third industries, and reduce carbon emissions while promoting industrial development; (4) Bengbu City has the second, first and third industries in the order of industrial correlation degree, and the second industry has a greater impact on carbon emission than other industries, which is consistent with the configuration analysis result path S1a. Emphasis should be placed on controlling the carbon emission of the second industry, accelerating the substitution of clean energy and the application of low-carbon technology in the industry; (5) From the perspective of industrial upgrading index, the correlation degree between industrial structure upgrading and carbon emission of old industrial cities in Anhui province is ranked from high to low as Huainan City, Huaibei City, Anqing City, Ma 'anshan City, Hefei City, Wuhu City and Bengbu City. Among them, Huainan City and Huaibei City have a higher correlation degree, and Bengbu City has a correlation degree less than 0.5, indicating that there is no obvious correlation between industrial structure upgrading and carbon emission, and it should develop stably within the current industrial structure.

Under the background of facing double pressure, the goal of industrial structure adjustment of the old industrial zone in our province to complete the adjustment and transformation plan of the old industrial base in 2022 has been nearly completed. At present, the industrial structure of the old industrial zone is relatively reasonable, and at the same time, it is in line with the results of the above configuration study. It should continue to lead the comprehensive green transformation of economic and social development, form a replicable low-carbon path experience, systematic planning, and a long time of success.

Table 8. Correlation between carbon emission and industrial structure of old industrial cities in Anhui Province

Regions	Proportion of primary industry	The proportion of the secondary industry	The proportion of tertiary industry	The proportion of tertiary and secondary industries	Relational order
	Relevancy	Relatedness	Relatedness	Relatedness	
Huaibei City	0.8626	0.8563	0.8589	0.8243	PI, TI, SI
Bengbu	0.6649	0.7661	0.6004	0.4917	SI, PI, TI
Huainan City	0.6690	0.6963	0.8125	0.8902	TI, SI, PI
Wuhu City	0.5848	0.6298	0.7828	0.6151	TI, SI, PI
Ma 'anshan	0.5076	0.5501	0.6966	0.7654	TI, SI, PI
Anqing	0.5992	0.6810	0.7649	0.7940	TI, SI, PI
Hefei City	0.6691	0.7237	0.8122	0.6190	TI, SI, PI

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6. Conclusion and Prospect

6.1. Conclusion

This paper takes 16 cities in Anhui province as research samples, and researches low-carbon path in a more specific and detailed way. fsQCA method is used to discuss the construction of low-carbon development path from the perspective of configuration, analyze the status quo of low-carbon development in each city, and clarify the direction of low-carbon reform by integrating four dimensions of economy, population structure, industrial structure and science and technology, including five conditional factors. Four urban low-carbon transformation paths of stable development and green production, promoting economic solid industry, industrial clean development and industrial service transformation were summarized, corresponding to the low-carbon transformation paths of different cities in Anhui Province with differences in economic development level, industrial structure and technical level. For the cities with stable economic development, control the population flow, pay attention to the adjustment of green development within the industry, improve the energy structure, pay attention to promoting the upgrading of industrial structure and the improvement of the level, and turn the industrial development to the sustainable development track with technological progress as the first driving force; For cities where economic development has no significant impact on carbon emissions and there are limits on scientific and technological level, it is necessary to promote the flow of population to cities, increase the size of the labor force, focus on promoting the green development of the city's secondary and tertiary industries, carry out low-carbon transformation of high-energy consumption industries, promote the upgrading of traditional industries, diversified development, and move closer to the high end of the value chain, so as to achieve low-carbon upgrading; For cities where carbon emissions are decoupled from high-quality economic development, a low-carbon industrial system may have initially taken shape, and population flow has little impact on low-carbon emissions. Promote the transformation and development of traditional resource-based industries to manufacturing, realize the transformation of intensive economic growth mode, and develop steadily within the current industrial structure. In addition, the adjustment and transformation of the old industrial city base has an important impact on low carbon emissions, and the impact of changes in industrial structure on carbon emissions will first drive the growth of carbon emissions and then reduce them. According to the correlation between industrial structure and carbon emissions of the old industrial cities in Anhui Province, the transformation of the old industrial cities has already achieved initial results and entered the stage of reducing carbon emissions. Most of the old industrial cities have a reasonable industrial structure.

6.2. Discussion and Reflection

According to the ecological and Environmental Status Communique of Anhui Province in 2020, carbon dioxide emissions per unit of GDP in 2020 will be reduced by more than 18 percent compared with 2015, fulfilling the 13th Five-Year Plan target. On December 7, 2022, the General Office of the Anhui Provincial Government issued the Notice on the Implementation Plan of Anhui Province's Carbon Peak. By 2025, the proportion of non-fossil energy consumption will reach more than 15.5%, the energy consumption per unit of GDP will be reduced by 14% compared with 2020, and the reduction of carbon dioxide emissions per unit of GDP will meet the targets set by the state. Based on the results of configuration analysis and grey correlation degree calculation, the following considerations are put forward:

The traditional advantageous industries are still the main part of its industrial economic development, and the low-carbon upgrading of traditional industries should be promoted. The low-carbon integration of new generation information technologies such as cloud computing, big data and the Internet of Things with traditional industries will be promoted around major

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competitive industries and pillar industries. We will strengthen support for resource factors, start with the steady development of industrial and supply chains, leverage the synergies of innovation, capital, service and talent chains, and accelerate the transformation of traditional industries with advantages into networked, digital and intelligent industries. For industries with high energy consumption, we will eliminate excess capacity, promote clean energy development and coupled substitution, and move up the value chain. In terms of macro-control, the government should provide a stable policy environment and active financial support for the development of traditional advantageous industries, and rely on modern information technology to lay the foundation for the transformation and development of traditional advantageous industries and the secondary development.

We should speed up technological transformation and intelligent manufacturing, and foster strategic emerging industries. We will vigorously foster the development of future industries, take core enterprises as the leading role, and enable the high-quality development of emerging enterprises and industries through science and technology. We will strengthen technological transformation and intelligent upgrading with enterprises as the main form, enhance innovation capacity and strengthen the principal position of emerging strategic industries, so as to support and promote the cluster development of emerging strategic industries. We will build industrial Internet platforms in frontier areas such as automation, new energy and new materials, promote industrial technological innovation, strengthen innovation capacity building, and jointly build emerging scientific and technological innovation industries. To sum up, industries with high energy consumption and high emissions can achieve the effect of energy conservation and emission reduction through multi-party extension of the internal industrial chain, and technological transformation and innovative development of resources accelerate the pace of industrial upgrading.

The path of urban low-carbon development in Anhui province should focus on the factors of economy, population, structure and science and technology, and should take multiple strategies simultaneously, taking into account the interaction of factors, play the "double carbon" goal to "green empowerment" of urban industrial structure in Anhui Province, promote the realization of low-carbon development of cities, and make contributions to promoting the construction of beautiful China in Anhui Province.

6.3. Deficiencies and Prospects

This paper also has the following deficiencies, which are worthy of further study in the future.

First of all, based on the existing studies, this paper only studies the four dimensions of economy, population, structure and science and technology, selects a limited number of indicator variables, and tries to find qualitative data for analysis. However, how to deepen the qualitative analysis still needs further discussion. Secondly, due to the availability of urban data and the convenience of research, this study only studied 16 cities in Anhui Province. There are differences in conditions, systems and development levels among provinces and cities across the country, which to some extent affect the generalization of the conclusion. More data on urban low-carbon emissions can be collected in the future. Further analyze the configuration (path) of influencing factors that produce low-carbon emissions. Finally, because there are few statistical data and studies on the influencing factors at the city level, this study only obtains static data by using QCA method. In the future, data can be collected across time, and a reasonable method can be adopted to dynamically study how the change "trajectory" of economic, population, structure and scientific and technological factors affects the change "trajectory" of low-carbon path.

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