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Abstract:

Based on data from 30 provinces in China, this paper builds evaluation models for a carbon emission-urbanization system that explores how to achieve low-carbon development during a rapid urbanization phase. Through mathematical and statistical analysis,principal component analysis and entropy evaluation methods are applied to calculate index weights for a comprehensive evaluation index of carbon emission-urbanization. A coordination degree model and a coupling coordination degree model (CCDM) are investigated as well. Scenario analyses on the coupling coordination degree of each province in different scenarios were applied to explain what would happen in different scenarios with the two systems. Case studies of four provinces were considered to illustrate the results, which show five basic conclusions. 1) Low-carbon development doesn't require eliminating energy consumption completely during urbanization since the overall coupling coordination level of low-carbon development and urbanization is not high in China. 2) The average level of urbanization in the 30 provinces examined is relatively low owing to the large disparities among provinces and the provinces' economic development. At the same time, though the development of low-carbon in the 30 provinces is generally rapid, the gap between the highest provinces and the lowest provinces is relatively large because of their different socio-economic features. 3) Much more attention should be paid to CO_2 emissions *per capita.* In doing so, the quality of public social service should be improved, and basic and medical insurance coverage for the elderly should be expanded. In addition, there is a need to focus on community service coverage in infrastructure—to strengthen resources optimization and environmental protection, and especially to encourage green design during urban construction. 4) The coordination of low-carbon development and new urbanization is closely related to the different development stages and geographic locations of each province. 5) For different types of provinces with different degrees of coupling coordination in the low-carbon development-new urbanization system, there is a need to explore different development directions.

Key words: low carbon cities; city carbon emissions; new pattern urbanization; coupling coordination

1.Introduction

Low-carbon development and urbanization are increasingly important issues in the field of climate change. Low carbon development is a mode of development which aims to achieve a low carbon economy through a process of de-carbonization, while contributing to sustainable development and tackling climate change(Feng,2015). Urbanization is the only way of modernization, an important way to solve the problem of agricultural and rural farmers and to expand domestic demand and promote industrial upgrading, a strong support to promote regional coordinated development. The urbanization in this paper refers to the new urbanization, which lead to more scientific layout and cleaner environment than the traditional urbanization. The rapid pace and intensity of urbanization, along with the urgent need for reducing carbon emissions (i.e., the greenhouse gases carbon dioxide (CO_2) and methane (CH_4)), has raised attention to these issues in academic and government circles, particularly in China. It is essential to explore methods to keep this rapid development sustainable, maintaining a high quality of living by coordinating urbanization and low-carbon development at the same time (Li et al., 2012). As a result, this paper, which analyzes recent trends in low-carbon development and urbanization in China, aims at exploring how to achieve a win-win situation between low-carbon development and urbanization. China's *National New Urbanization Plan* (2014 - 2020), promulgated March 27, 2014, defines the basic principles of a new type of urbanization as "ecological civilization—green and low carbon," and it proposes a new urbanization evaluation system. Urbanization, along with lifestyle changes of urban dwellers in China, has led to a substantial increase in both energy consumption *per capita* and greenhouse gas emissions in absolute terms. The consequence is that the urban environment is also facing increasing pressure from it. In addition to direct energy consumption by growing urban populations, the related construction, transportation, and industrial production are using high levels of energy and contributing to higher concentrations of GHG in the atmosphere (Guo et al., 2010).

Different patterns of urbanization yield varying levels of carbon emissions. In approporiate or inefficient urbanization practices result in higher carbon emissions (Gu et al., 2009). Thus it is crucial to develop a scientific method for evaluating how urbanization practices can minimize energy use and carbon emissions. This paper evaluates case studies from 13 municipalities in Jiangsu Province, evaluating five aspects of urbanization: economics, spatial patterns, population, lifestyles, and quality of life (Ou et al., 2004). In doing so, Zenglin Han（2009）examined the index of urbanization quality,which includes economic development, infrastructure, employment, citizen life, social development, environment, land use quality, innovation quality, and urban-rural income gap (Han et al., 2009). The *National New Urbanization Plan* strongly promotes aggressive urbanization policy, supporting and encouraging sustainable development, by providing best practices for the environment of low-carbon urban centers. This effort shows the current Chinese government's focus on achieving sustainable development, finding a way to use low-carbon development in the trend to urbanization. In 2009, Zhilin Liu provided a new model of sustainable urbanization for China, which integrated both elements of low-carbon economy and low-carbon society (Liu et al., 2009). Boqiang Lin (2010) also made amendments to Kaya identity（an identity stating that the total emission level of the greenhouse gas carbon dioxide can be expressed as the product of four factors: human population, GDP per capita, energy intensity, and carbon intensity） by introducing the effect of urbanization to the factors affecting carbon dioxide emissions in the current development stage (Lin et al., 2010).

Low-carbon development is necessary to offset the negative impacts of increased urbanization in China. Theoretical and empirical works in the past do not reach a solution/conlusion about the relationship between low-carbon development and urbanization. This paper seeks to fill this research gap by using 2013's China province-level dataset. First of all, this article has theoretically enriched the relationship between urbanization and low-carbon development. Most of the existed researches paid more attention to the relationship between the speed of urbanization and the amount of carbon emissions, while urbanization and low-carbon development need more attention on quality. This paper is based on the quantitative evaluation of the relationship between urbanization level and low carbon development level, which are more scientific. Secondly, this paper uses the CCDM model to calculate the relationship between the low carbon development level and the urbanization level, which is the first use of CCDM methods for research on low-carbon development and urbanization. Thirdly, the evaluation of the urbanization level in the past is based on the individual influencing factors, this article, which use evaluated criteria in the 2014 *National New Urbanization Planning* for urbanization assessment, is relatively objective and scientific. And for the evaluation of low-carbon development level, the previous study had some shortages. For example, some studies were only focus on carbon intensity and energy intensity but ignore the economic factors (Zhu, 2010), some had more variables and incomplete data (Ma and Luo, 2011), and some used expert scoring method to determine the subjective weight of the index (Chen, 2016). And this article use LBNL indicators, can clearly reflect low-carbon development level in transportation, construction, industry, and society, and effectively avoid the above problems. To sum up, this article expands the current research of the relationship between low-carbon development level and urbanization level from the theoretical and methodological index system construction.

"Coupling," a phenomenon originating in the physical sciences, is when two or more systems influence each other through various interactions. Coupling is now widely used in studies of climate change and urbanization (Li et al., 2016; Li et al., 2012). Additionally, empirical studies have focused on the nonlinear relationship between urbanization, environmental Kuznet curves (EKC), and the environment. However, a lack of data is an obstacle for research on the relationship between carbon emissions and urbanization, especially in China.

The coupling coordination degree model (CCDM) proposed in this study was designed to: 1) reveal the current average development level of carbon emissions and urbanization in the 30 provinces; 2) identify the indicators which made the greatest contribution to the two systems in the CCDM, balancing low carbon development and urban development during macro policy-making to increase carbon emission and urbanization quality rather than the rate of urbanization; 3) evaluate the current level and development of the coupling of low carbon and urbanization; 4) explore different influences on the parameters of the coupling model in different provinces.

2.Data and Methodology

Many researchers have studied the urbanization index system and presented different evaluated indicators. Using three indicators from the index—systemic, integrity, and availability of data—Zenglin Han and Tianbao Liu evaluated urbanization quality from 10 aspects, such as economic development, infrastructure contribution, employment, urban residents' living, social development, ecological environment, land quality, innovation quality, and coordination of urban and rural (Han and Liu , 2009).

Here, according to the quantitative indicators， an indicator system that can measure the quality of urbanization, outlined in *National New Urbanization Planning* (2014-2020), this study evaluated indicators including demographic aspects (urbanization rate), public social services (unemployment rate, basic pension insurance coverage in urban resident population, basic medical insurance coverage in urban resident populations), infrastructure (public transportation accounts for the largest proportion of transport, urban public water supply coverage, urban sewage treatment capacity, living garbage treatment capacity, urban households broadband access broadband subscribers, community service coverage), and environment (urban green land share, urban construction land *per capita*). Entropy value for each index was used to determine an urbanization score. Considering the suitability and availability of data, the unemployment rate rather than the compulsory education and basic vocational skills training coverage of migrant workers' children is used in our paper. Because there is no index data at the provincial level for affordable housing, renewable energy consumption, and green buildings, and alternative indicators were not identified, these are not mentioned in the evaluation system.

Many domestic and foreign researchers have measured Chinese low-carbon development using various index systems. For example, the low-carbon city index system (LCCC)(Chinese Academy of Social Science, 2013) contains five major categories and 15 indicators that can measure low-carbon development, including aspects such as economy (carbon productivity, energy intensity and decoupling index), energy (non-fossil energy proportion, renewable energy consumption *per capita* and carbon energy intensity), establishment (public buildings' carbon emissions per unit of area, public transport accounts), environment (air quality, urban public water supply, forest coverage), and society (income ratio between urban and rural residents, carbon emissions *per capita* and urban low-carbon management system).

Due to the availability of data at the provincial level, this article used the evaluation system created by the Lawrence Berkeley National Laboratory

(LBNL)(Zhou et al., 2012; Zhou et al., 2015; Zhou and Williams, 2013).The system has a clear vision of what defines a low carbon development. Those selected indicators reflect the connection to different low carbon vision(economy (energy consumption per unit of gross domestic produce or GDP), population (CO_2 emissions *per capita*), residence (residential final energy), commerce (commercial final energy), industry (industrial final energy), transportation (transportation final energy) and electricity (CO_2 per power produced)). They are based on data availability and given consideration of local situation. They are embedded to the governance structure and institutional capability so the implementation is not only possible but also sustainable. With careful examination and detailed comparison, we use a comprehensive, comparable, and adaptive indicator system which developed by LBNL to evaluate the low carbon development.

Table 1. The index of low-carbon development system and urbanization system

System	Sub-System	Index
Low-Carbon Development	Economy	Energy consumption per unit of GDP(Tce/ten thousand yuan)

System	Population	CO_2 emissions *per capita*(tons per person)
	Residence	Residential Final Energy/Capita(Tce/sqm)
	Commerce	Commercial Final Energy/Employee*(Tce/per person)
	Industry	Industrial Final Energy/Industry GDP(Tce/Yuan)
	Transportation	Transportation Final Energy/Capital(Tce/per person)
	Electricity	CO_2 per power produced(KWh/ten thousand yuan)
Urbanization System	Demographic aspects	Urbanization rate(%)
	Public social service	Unemployment rate(%)
		Urban resident population of basic pension insurance coverage(%)
		The resident population of the basic medical insurance coverage(%)
	Infrastructure	Public transportation's proportion in city

		transportation(%)
		Urban public water supply coverage (cubic meters / day))
		Urban sewage treatment capacity (ten thousand cubic meters)
		Life garbage treatment capacity (tons / day)
		urban households broadband access broadband Subscribers (million)
		Community service coverage (%)
	Environment	Urban green land share(%)
		urban construction land per capital(m^2/per capita)

The required data were collected from the statistical yearbooks (2014) of 30 provinces and the *China Energy Statistical Yearbook* 2014. Data was standardized using formulas (1) and (2) and eliminated the influence of dimension, magnitude, and positive and negative orientation.

Positive indicator : $y_j = (x_j - x_{j\max}) / (x_{j\max} - x_{j\min})$ (1)

Negative indicator: $y_j = (x_{j\max} - x_j) / (x_{j\max} - x_{j\min})$ (2)

where x_j represents the value of indicator j, and $x_{j\max}$ and $x_{j\min}$ indicate the maximum and minimum value of the indicator, respectively. Meanwhile, to ensure a bigger system index score to represent a better index level, two methods were chosen—the positive indicator and the negative indicator—for data processing.

The steps to get the index weight by entropy value method are as follows:

Firstly, to calculate the sample index weight:

$$p_{ij} = x_{ij} / \sum_{i=1}^{m} x_{ij} \quad (3)$$

In the formula above, m is the total number of samples.

Secondly, to calculate the entropy of j indicator:

$$e_j = -k \sum_{i=1}^{m} p_{ij} \cdot \ln p_{ij} \quad (4)$$

In the formula, the constant k is related to the sample m: k=1/*ln*m, then $0 \le e \le 1$.

Thirdly, to calculate the utility value of each index:

$$d_j = 1 - e_j \tag{5}$$

The larger d_j is, the more valuable the index x_j is , and its weight is accordingly greater.

Finally, to calculate the index weight of x_j.

$$w_j = d_j / \sum_{j=1}^{n} d_j \tag{6}$$

1.The coordination of urbanization systems and low-carbon development systems

The level of urbanization and low-carbon development systems is the result of coordination between these two systems. And the usual coordination measuring method is to measure the size of of the distance between the static system and judge the coordination degree. Here F and G are selected, which respectively represent the urbanization system and the low-carbon development system. F(x) and G(x) measure the development level, with the index x representing the urbanization system, and the index y representing the low-carbon development system. The coordination degree of these systems refers to the relative dispersion coefficient. When the relative dispersion coefficient is smaller, the coordination degree is higher. Formulas (7) and (8):

$$c = \frac{2\left|F(x,t) - G(y,t)\right|}{F(x,t) + G(y,t)} \tag{7}$$

Transfroms formula (7) to formula (8)

$$c = 2\sqrt{1 - \frac{F(x,t) \times G(y,t)}{\left[\frac{F(x,t) + G(y,t)}{2}\right]^2}} \tag{8}$$

$$cl_1 = \frac{F(x,t) \times G(y,t)}{[\frac{F(x,t) + G(y,t)}{2}]^2} \tag{9}$$

With the calculation $F(x,t) \times G(y,t) \leq [\frac{F(x,t) + G(y,t)}{2}]^2$, a conclusion results: when cl_1 is bigger，c is smaller，and the coordination between F and G are greater. Obviously when F(x)=G(x), the two systems are in the same relative level, and the index cl_1 get maximum score and the index c=0, which means the relative dispersion coefficient get a minimum score and F and G are in the best coordinate situation. Therefore, the model is simplified, and the coordination level of these two systems is measured through the score of the index cl_1.

2.Assessment of the degree of the coupling and coordination of urbanization and low-carbon development systems

The concept of coupling function originates from the physical sciences, and it can be used to compare multiple systems by establishing the coupling degree model of the interaction between multiple systems. Variable Ui (i=1,2,…,n) was used to represent the system and promote the coupling degree model of the interaction between multiple systems.

$$c_n = n\left[\frac{(u_1 u_2 \ldots u_n)}{\prod\left(u_i + u_j\right)}\right]^{1/n} \tag{10}$$

where the numerator is the arithmetic product of each subsystem's overall contribution (Ui), the denominator is the arithmetic product of the sum of every two subsystems' overall contribution; then, the quotient extracts "n" roots. Through these mathematical calculations, the subsystems' mutual relationships are combined, which reveals the system's degree of coupling. The degree of coupling is decided by the score of each subsystem Ui. In this paper, there are two subsystems in the coupling analysis, so n=2, as the formula (11) shows:

$$c_2 = 2\left[\frac{u_1 u_2}{\left(u_1 + u_2\right)^2}\right]^{1/2} \tag{11}$$

Compare the index cl_1 with index c_2 in this case, and the coordination degree of the urbanization system and low-carbon system can be defined as formula (12)

$$cl = \left(\frac{F \times G}{(\frac{F+G}{2})^2}\right)^2 \tag{12}$$

the index cl infers by c_2 and cl_1. Considering the relative dispersion coefficient formula, cl is selected to represent the coordination level that will increase the layering of the data.

According to formula (12), $0 \leqslant cl \leqslant 1$ becomes clear, which means the coupling score is between 0 and 1. When cl=1, the degree of coupling is the largest, and the system has benign resonance and can work into a orderly new structure. When cl=0, the degree of coupling is the smallest, and one subsystem and another (or one element and another) will be uncorrelated; the coupling system will tend to be disordered.

Based on a review of relevant research, the median partition method was used. When $0 < cl \leq 0.4$, the urbanization and low-carbon development subsystems are in the low-level coupling state; when $0.4 < cl \leq 0.7$, the urbanization and low-carbon development subsystems are in the rivaling state; and when $0.7 < cl \leq 1$, the urbanization and low-carbon development subsystems are in the high-level coupling state.

The index cl can represent the coordination level of urbanization and low-carbon systems. However, when the development degree of these two systems are not in the same level, it is difficult for this model to represent the actual level between the two systems. For example, in some provinces, when urbanization system levels and low-carbon system levels are both low, and the coordination degree is higher than the situation that the urbanization system level is high and the low-carbon system level is low. This conclusion varies from expectation, because the goal of this study was to reflect the rapid and harmonious development of urbanization and low-carbon systems through the coordination degree. To avoid the emergence of this situation, the development level of two subsystems was input into this model to construct the coupling coordination degree model of urbanization system and low-carbon development system. Thus, the coupling coordination degree of two systems in different provinces can be evaluated and the coupling coordination degree can reflect the relatively level of the two systems at the same time. For this specific model, a new variable T was added to represent the comprehensive evaluation index of the urbanization and low-carbon development system, which can be calculated as follows:

$$T=\alpha F\left(x,t\right)+\beta G\left(y,t\right) \tag{13}$$

$$D=\sqrt{cl\times T} \tag{14}$$

Where D is the degree of coordination, cl is the degree of coupling, and T is the comprehensive coordinating index of urbanization and low-carbon development, which reflects the effect or contribution of integrated synergy of urbanization and low-carbon development. Both α and β are weights to be determined. Three situation are compared in the model: (1) α=β=0.5 (2)α=1/3,β=2/3 (3)α=2/3,β=1/3.

According to the distribution of F and G, the value of the comprehensive efficacy of the subsystem, or the value of the degree of coordination D, is between 0 and 1.

The higher the comprehensive efficacies that the urbanization and low-carbon development subsystems contribute to the whole system, the higher the value of the degree of coupling and coordination will be. Additionally, the better the urbanization and low-carbon development subsystems, the more harmonious their relationship is.

3.Results

3.1 The level of low-carbon development and urbanization in each province

1. The low-carbon development level of each province

As shown in Figure 1, Anhui, Jiangxi, and Hainan are the top three cities and Inner Mengolia, Xinjiang, and Ningxia are at the bottom in the rank of level of low-carbon development. The average level is 0.73, a relatively high level, which means that the provinces in the eastern China are at a higher level, while the provinces in western China are at a lower level. Except for the last four provinces, the difference is not significant.

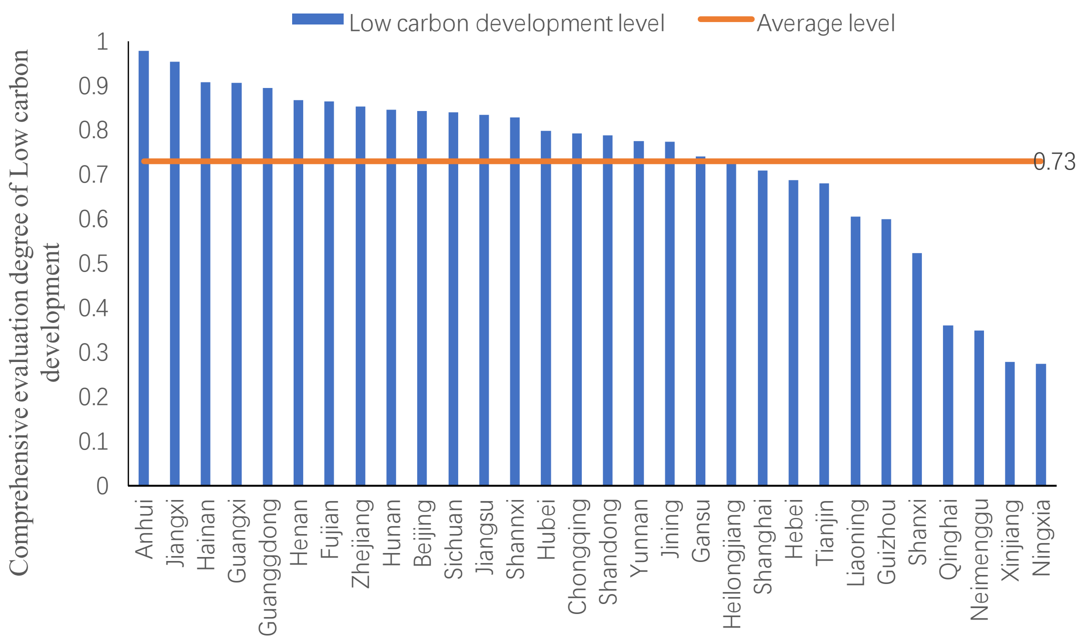

Fig 1. Levels of low-carbon development in different provinces

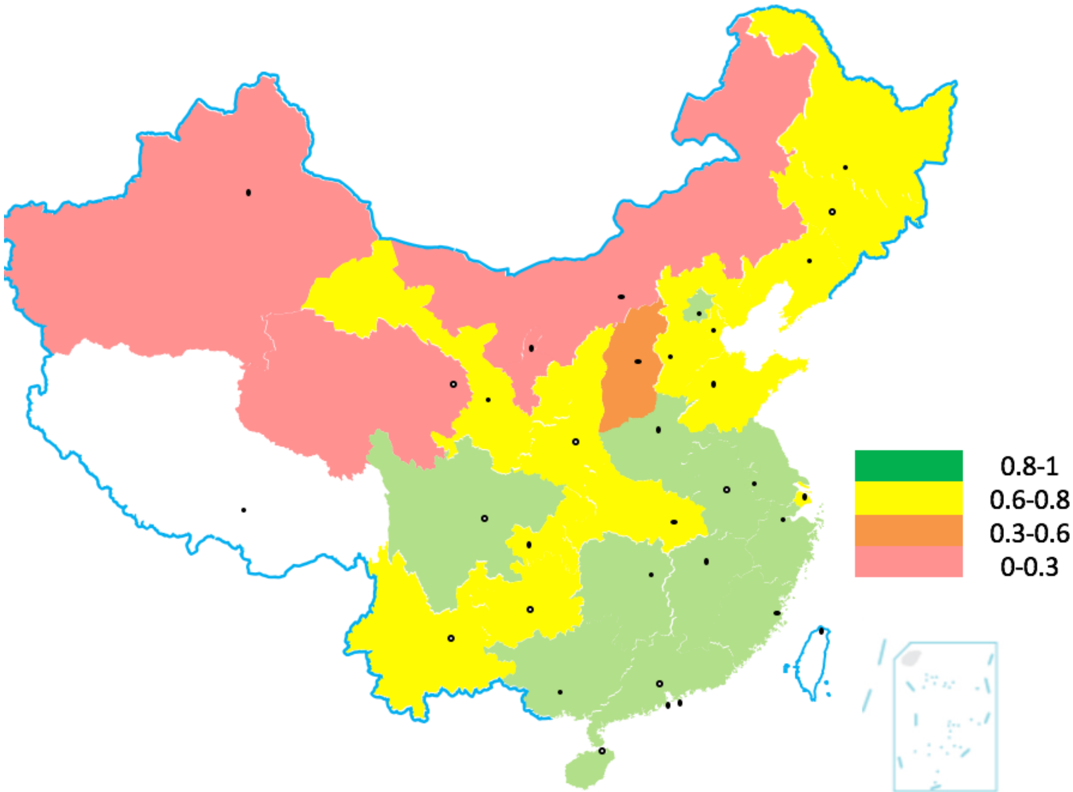

Fig 2. Levels of low-carbon development in China

2. The urbanization development level of each province

As shown in Figure 2, levels of low-carbon development vary significantly across provinces. Beijing ranks the first, Shanghai and Guangdong follow, and Guizhou, Yunnan, and Gansu rank the last in the level of urbanization development. The average of level of urbanization development is 0.46, a relatively low level, which shows that, for the provinces with a higher GDP, urbanization development levels are higher as well.

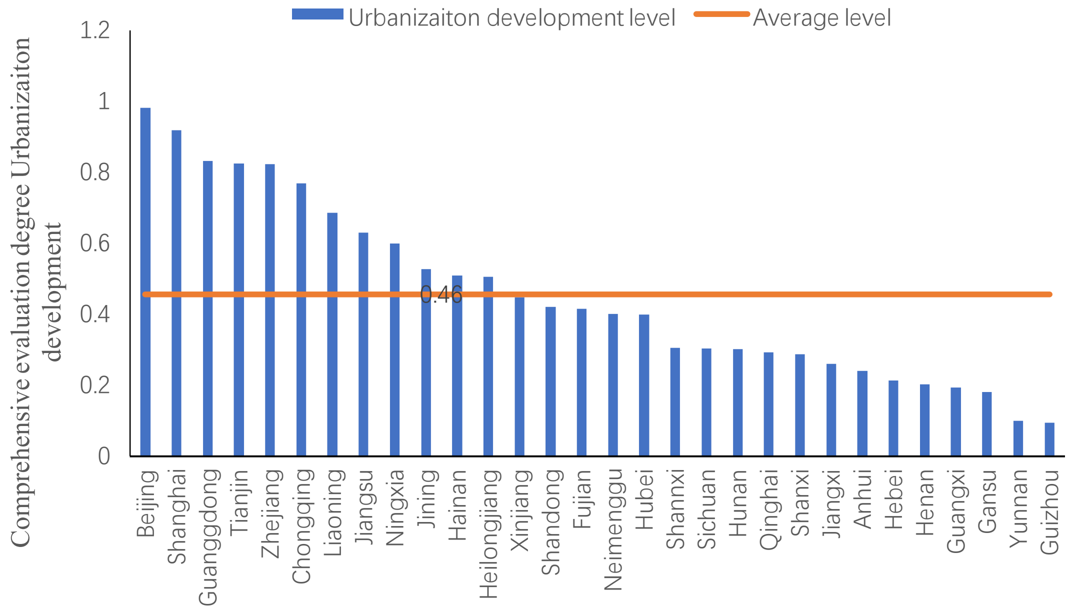

Fig 3. Level of urbanization development in different provinces

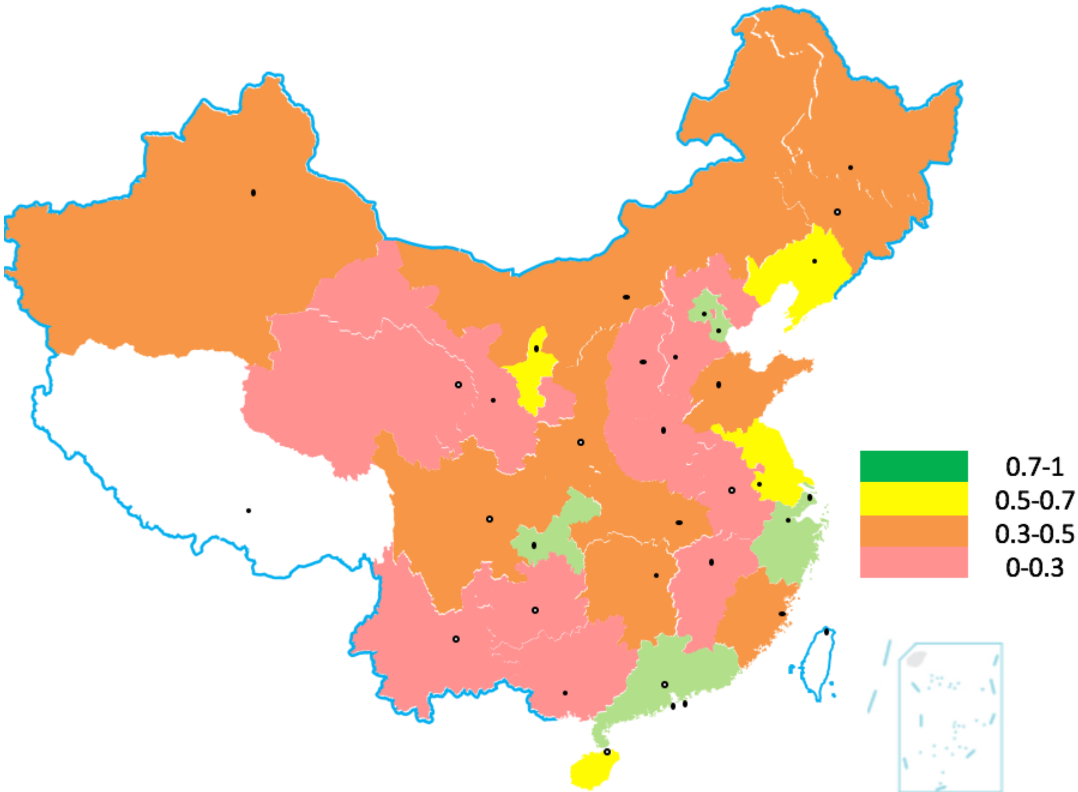

Fig 4. Level of urbanization in China

3.2 Coupling coordination degree of each province

According to the level of urbanization and low-carbon development, different weights are used to try to reduce the influence of the artificial weight assignment method on the experimental results. This study uses three kinds of situations to discuss urbanization and low-carbon city development: $\alpha = 1/2$, $\beta = 1/2$; $\alpha = 1/3$, $\beta = 2/3$; $\alpha = 2/3$, $\beta = 1 / 3$.

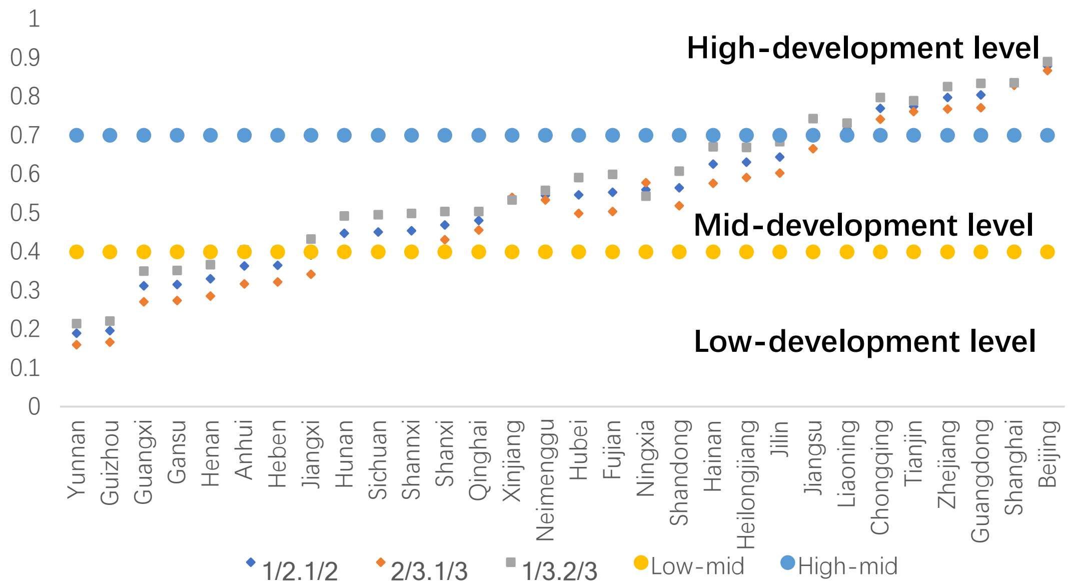

Fig 5. Coupling coordination degree in three development levels

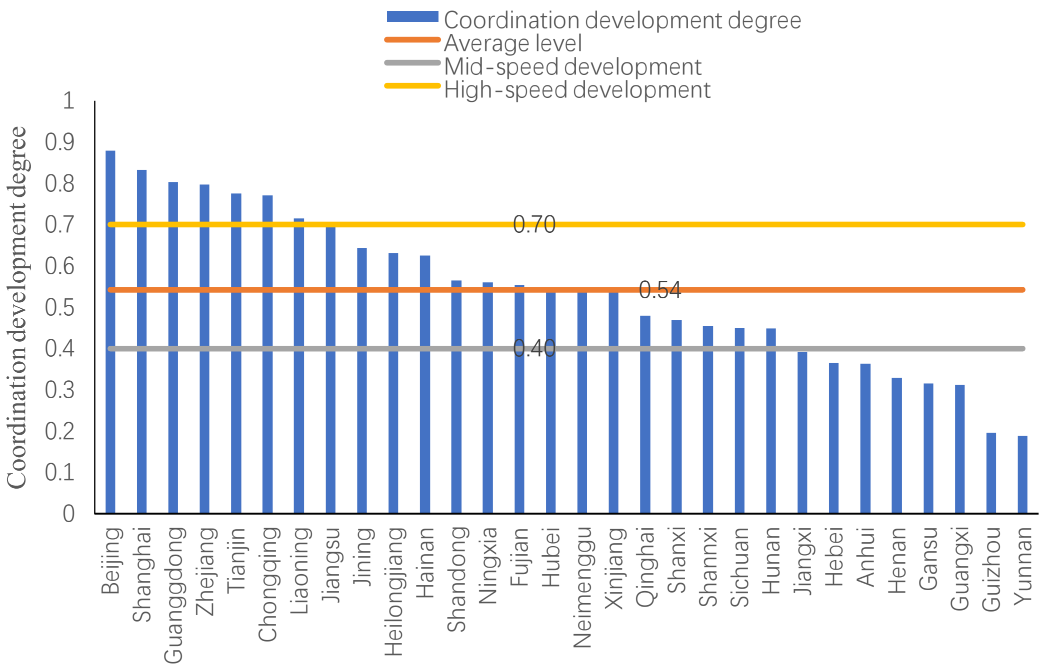

Fig 6. Level of coupling coordination in different provinces

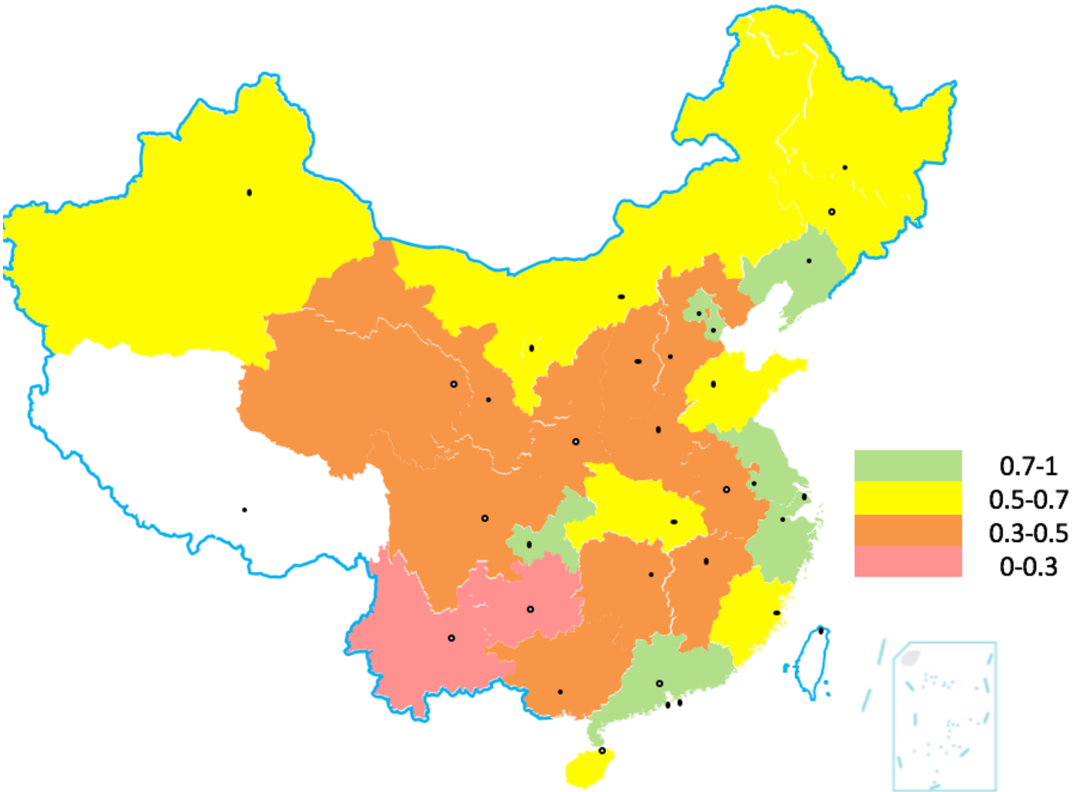

Fig 7. Level of coupling coordination in China

From the above figure, **we can draw the following conclusions:**

1. Under the three weighting methods, except for Ningxia, other provinces' and cities' degrees of coordinated development will reach the maximum when α = 1/3 and β = 2/3, and will reach the minimum value when α = 2/3, β = 1/3. The above conclusion indicates that the greater the proportion of low-carbon development, urbanization and low-carbon development are, the higher degree of coordinated development is. Low-carbon development system insert a great

impact on a province's degree of coordinated development between urbanization and low-carbon development. Taking Ningxia as a special case, we will discuss the case in the fourth part.

2.Among the three levels of coordination, the majority of the provinces belong to the moderate degree of coordinated development . Beijing, Guangdong, Shanghai, Zhejiang, Jiangsu, Liaoning, Tianjin and Chongqing all have a high degree of coordinated development. The results show that the degree of coordination between the urbanization and low-carbon is lower than 0.4 in the three provinces of Guizhou, Yunnan, Gansu and Guangxi. The results also show that the degree of coordination is lower than 0.4, its urbanization and low-carbon construction level is low, or different.

3. Coupling coordination degree can better reflect the two systems' comprehensive development. The results show that Xinjiang, Inner Mongolia, and Ningxia's urbanization system and low-carbon construction system coordination are the highest: the coupling coordination degree is between 0.4 and 0.7. The reason is that urbanization levels in these three provinces are very close to the

low-carbon construction level, but they are all at the low development level. Therefore, their scores are relatively high when calculating the coordination degree. The comprehensive score of the two systems is included in the final calculation method. Due to the low score of the system, the degree of coordination in the three provinces is reduced by a grade of coordination, which brings the levels back to a moderate degree of coordinated development. Figure 8 the coupling degree in the coordination model is more objective to reflect the comprehensive development degree of two systems in a province,it is the key point that we need attention and promotion.

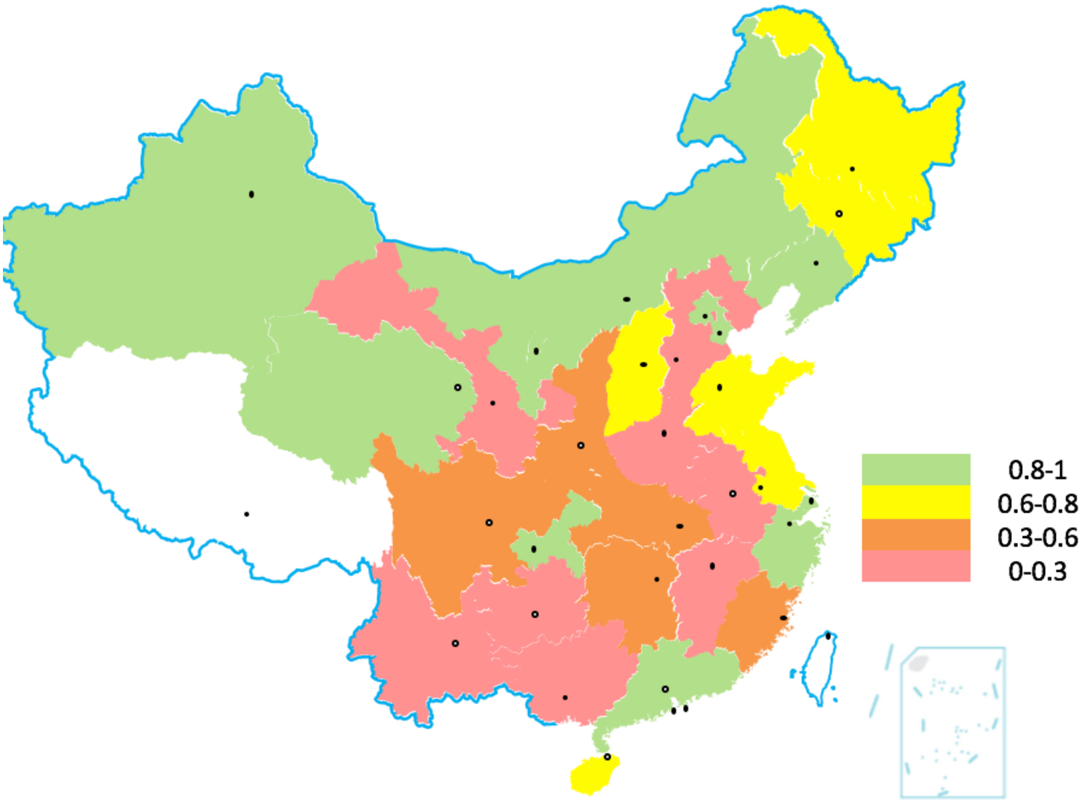

Fig 8. Level of coordination degree in China

3.3 The influence factor of low-carbon urbanization a development system

Through the pre-processing data and entropy method, the weight of each index in the system becomes clear, as shown in Table 2.

Table 2. Low-carbon development and urbanization

System	Sub-System	Index	Contribution
Low-Carbon Development System	Economic	Energy consumption per unit of GDP(Tce/ten thousand yuan)	0.2068
	Population	CO_2 emissions per capita(Tons/s/per person)	0.2188
	Residential	Residential Final Energy/Capita*(Tce/sqm)	0.0725
	Commercial	Commercial Final Energy/Employee*(Tce/per person)	0.1596
	Industrial	Industrial Final Energy/Industry	0.0769

		GDP(Tce/Yuan)	
	Transportation	Transportation Final Energy/Capital(Tce/per person)	0.1006
	Electricity	CO_2 per power produced(KWh/ten thousand yuan)	0.1648
Urbanization System	Demographic aspects	Urbanization rate(%)	0.0883
	Public social service	unemployment rate(%)	0.0637
		Urban resident population of basic pension insurance coverage(%)	0.0651
		The resident population of the basic medical insurance coverage(%)	0.1463
	Infrastructure	Public transport accounts for the proportion of transport(%)	0.0454
		Urban public water supply coverage (cubic meters / day))	0.0671

		Urban sewage treatment capacity (ten thousand cubic meters)	0.0719
		Life garbage treatment capacity (tons / day)	0.0692
		urban households broadband access broadband subscribers (million)	0.0215
		Community service coverage (%)	0.1773
	Environment	urban green land share(%)	0.1308
		urban construction land per capital(sq.m/per person)	0.0533

Table 2 shows seven sub-indicators. In the low-carbon development system, the weight of CO_2 emissions *per capita* is 0.2188, and energy consumption per unit of GDP is weighted at 0.2068. This means that CO_2 emissions *per capita* and energy consumption per unit of GDP have had a profound effect on the low carbon-urbanization development system. For other indicators, CO_2 per power produced, Commercial Final Energy/Employee and Transportation Final Energy/Capital, Industrial Final Energy/Industry GDP and Residential Final Energy/square respectively are weighted at 0.1648,0.1596, 0.1006, 0.0769, and 0.0725. In the urbanization system, and in sub-system public social service, unemployment and urban resident population of basic pension insurance coverage have the biggest effect. Public transport's proportion of transport and urban households broadband access broadband subscribers account highly for the infrastructure sector.

While community service coverage weights 0.1773 and the resident population of the basic medical insurance coverage, and urban green land share weight 0.1463, 0.1308, respectively, community service coverage, the resident population of the basic medical insurance coverage and urban green land share dramatically affected the low carbon development - urbanization development system.

4.Case study

4.1 Coupling coordination

As shown, the average urbanization level is 0.46. This proves that most provinces' urbanization comprehensive score in China are still in the low levels, and there is room for further development. The urbanization levels of the four provinces of Guangxi, Gansu, Yunnan, and Guizhou are below 0.2. Their development indicators are in the low level, indicating that the level of urbanization needs to be improved. At the same time, these four provinces are also located in the low level of coordinated development among the four provinces, showing that a low level of urbanization development largely affected the degree of their harmonious development in the final estimates.

The average low-carbon development level is 0.73, and this result is contrary to our expectations. Most of the provinces and cities with low-carbon development have achieved good results. Anhui, Jiangxi, Hainan, Guangxi, and other provinces' integrated levels of low-carbon development have reached more than 0.9. This may be related to the inclination of promoting low-carbon city construction in these provinces., with an aim to reach carbon dioxide emissions peak target by the year 2030. The provinces and cities, driven by national goals combined with their own efforts, quickly developed low-carbon city construction practices. The five provinces with best low-carbon development scores are Shaanxi, Qinghai, Inner Mongolia, Xinjiang, and Ningxia. These five provinces are located in the northwest, with dry climates in desert and Gobi areas, which may be good lacations for the development of heavy industry. Such industry would cause the high-level carbon emission.

Four typical case studies are presented below: 1) Ningxia: high level of urbanization but low level of low-carbon construction; 2) Anhui: low-carbon construction level is relatively high but low level of urbanization; 3) Beijing: level of urbanization and low-carbon construction both at high levels; 4) Guizhou: urbanization and low-carbon construction both at low levels.

Ningxia is located in the northwest of China and is a gathering area for ethnic minorities. In recent years, Ningxia's autonomous region has been adhering to new industrialization, information technology, and agricultural modernization. The region has been promoting new urban construction, constructing new infrastructure, promoting industrial development, starting trade logistics projects, and accelerating population, industry, resources and other elements for urban development. Due to the non-agricultural population reduction, urbanization levels also tend to be improved. At the same time, Ningxia's geographical location has led to issues such as serious soil erosion, desertification, air pollution, water pollution, soil pollution, and heavy metal pollution. Therefore, the low-carbon development level is low, and there is still a long way to go. Through new urbanization and optimization of energy consumption and other measures, low-carbon levels can be improved.

Anhui is located in the middle and lower reaches of the Yangtze River Basin,which is near to Jiangsu, Zhejiang, and other developed provinces in the east of China. There are many mountainous areas in Anhui Province, with great forests, providing great potential for forestry and agriculture development—and playing an important role in promoting the development of low-carbon economy in Anhui Province. At the same time, automobile manufacturing constitutes the main economic development industry in Anhui. In recent years, reduced fuel consumption in civilian cars, and new cars with low-emissions, energy savings, and environmental protection have improved the efficiency of new vehicles, playing a significant role in upgrading the low-carbon development level of Anhui. Thus, the low-carbon development level in Anhui Province is high. Considering the level of urbanization, as well as terrain restrictions and regional restrictions, Anhui's population and industrial development pace is inconsistent, industrial restructuring has not yet formed industry development effects, the secondary industry doesn’t reach the national average level, the development of third industry is slow, and urban and rural dual structure and more stringent household registration management systems also curb the process of urbanization in Anhui Province. Therefore, Anhui Province has been in a relatively low level of urbanization compared to the level of the low-carbon development.

Beijing, located in the eastern developed areas, is the capital of China, and is also China's political and cultural center. Beijing’s better infrastructure and more reasonable urban industrial structure, the percentage of tertiary industry in Beijing is 80.3%, 30% higher than the national average level respectively, lead to a higher level of urbanization. Similarly, total energy consumption in Beijing is growing more slowly than the GDP. Beijing’s overall development is relatively energy efficient, with energy consumption, industrial and *per capita* carbon emissions, carbon productivity, and other indicators at very high levels. Beijing is also one of the first national low-carbon pilot cities, and capital investment and policy support have made its low-carbon development levels higher, surpassing the national average.

Guizhou is located in the southwest of China. It has a low level of industrial development, and the agricultural population is relatively large. Its economic level is low because it is located in the Yunnan-Guizhou Plateau where transportation is difficult to develop and land for industrial development is lacking. Its infrastructure construction is poor, too, so that the level of urbanization is accordingly lower. Although the forest coverage in Guizhou is higher than some other provinces, energy consumed for economic and social development as well as industrial energy consumption has increased rapidly because of the low level of urbanization. This has led to an increase in *per capita* carbon emissions and other indicators; the province's energy structure and energy efficiency is still inadequate. Therefore, low-carbon development level is also low.

4.2 Impacts of the coordination degree

For the low-carbon development system, the three most important indicies are carbon dioxide *per capita*, energy consumption per unit of GDP, and CO_2 per unit of electricity produced.

Carbon dioxide consumption *per capita* is the ratio of the total carbon dioxide emissions to the population of the province, which reflects the emission levels of all aspects of social life. In data from 30 provinces, the best performance comes from Jiangxi Province, with its 4.96 tons of emission *per capita*. Inner Mongolia, as an industrial and powerful generation province, has the highest CO2 emissions *per capita* in the country (22.52 tons), compared with the national average emission level (10.88 tons). The difference between the maximum value and the minimum value is significant, which indicates that development levels in each province and the *per capita* emission control situations are quite different. In the northwest area such as Inner Mongolia, Ningxia, and Xinjiang, where are the base for energy production and supply for the entire country, including coal, oil and natural gas, vegetation is poor and industrial emissions is high. There is much room for improvement.

Energy consumption per unit of GDP is also an important index for evaluating low-carbon level, which comprehensively reflects the energy consumption situation in economic growth. In 2014, the national average energy consumption per unit of GDP in China was 1.006 tons per 10,000 Yuan, 2.2 times the world average, despite in Beijing, Shanghai, Guangdong, and other developed eastern provinces, the index scores are better. The index score in Beijing is 0.437, basically the same as the world's average. At the same time, Qinghai, Ningxia, Xinjiang, and other northwest provinces result in higher energy consumption per unit of GDP due to heavy industry, coal-fired power generation, and other reasons. The index score in Ningxia reached 2.206, two times the national average level. The poorer-performing provinces should focus on improving the energy consumption through the development of clean energy, industrial transformation, and other methods.

Carbon dioxide emissions per unit of electricity production shows the relationship between power generation and carbon dioxide emissions, and is also an index of the provincial power generation structure. The share of the fossil energy power generation in a power structure directly affects carbon dioxide emissions. Renewable and nulear energy development can greatly reduce the value of this index. At present, average emissions in China's 30 provinces is 1.037 kg / kWh; emissions in Beijing, Jilin, and Tianjin show better performance. The emission in Beijing is 0.461 kg / kWh. Emissions in Qinghai, Ningxia, Xinjiang, and other northwestern regions are high due to the coal-fired power generation and larger transport processes. Emissions in Qinghai are 3.186 kg / kWh, three times the national average. These provinces need to focus on improvement.

For urbanization, the three indicies with the greatest influence are: basic medical insurance coverage rate, community service organization(containing Nursing homes and community hospitals and so on) coverage rate, and the built-up area green-land coverage rate, among which the community service organization coverage ratio is the largest.

Community service refers to the public service and other material, cultural, and life services provided by the government, community neighborhood committee, and other forces directly for the members of society, including medical and health services, life services, children and children services and social welfare services. It is an important part of the process of urbanization, and provides an important part of the quality of life of community residents. According to the data in 2014, comprehensive urban community service in China is 40%, lower than the world average, and the difference between regions in China is very large. The coverage rate in Guangdong is 175% (considering different types of community services), which is the highest in the country, and Yunnan, Qinghai, and other western provinces have community service coverage still less than 10%, mainly due to the mountainous rural population (community services in remote areas can not meet normal living requirements). Therefore, the proportion of community services can reflect the level of urbanization and has become an important factor in urbanization evaluation.

Basic medical insurance coverage refers to the proportion of urban residents who purchased medical insurance. The medical security is the most important part of the social security system, which is related to the personal health of the residents. Medical resources is important in the process of urbanization development. According to 2014 data, the coverage rate of medical insurance in Chongqing, Guangdong, and Zhejiang provinces has reached 100%, while the coverage rate of basic medical insurance for resident population in southern China such as Guizhou, Guangxi, and Fujian is still less than 60%. One of the key issues in the next stage of development should be health coverage for migrant workers.

Urban green coverage rate refers to the coverage ratio of plants, including shrubs and herbs, in urban areas. Under the background of new urbanization construction and low-carbon urbanization development, green coverage rates directly affect living comfortability and have a great influence on urban residents' quality of life. In 2014, the greening rate in urban areas in 30 Chinese provinces was about 38.79%; the greening coverage rate in Beijing reached 47.1%, the highest level among 30 provinces. The greening coverage rate in Jilin and Qinghai provinces is only 31.2%. In recent years, little attention has been paid to protecting vegetation during rapid expansion of urban centers, resulting in shrinking areas of urban greenery. This indicator is also closely associated with the low-carbon combination, showing that low-carbon living during the process of urbanization also occupies an important position.

5. Key findings and discussion

Since no development can be done entirely without energy consumption during urbanization, the coupling coordination level of low-carbon development and urbanization is not high in China. Of 30 provinces, 23% are at a relatively high level, higher than 0.7, 27% of 30 provinces are at a relatively low level,lower than 0.4, and 50% of provinces occupy the midium level, between 0.4 and 0.7. The provinces with the midum and low levels accout for 77%, which shows that development should ensure minmimal dependence on energy consumption during urbanization.

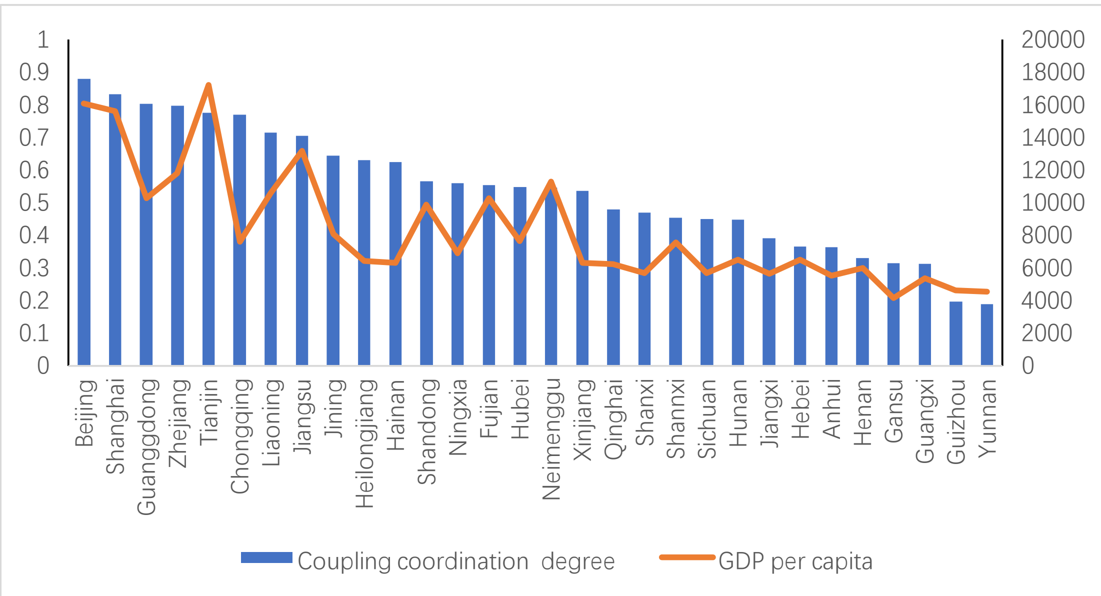

Figure 9. The coupling coordination delopment and GDP per capita in 30 provinces

Overall urbanization levels in the 30 provinces are relatively low, and there is a large disparity among those provinces owing to varying levels of economic development. The average level of urbanization in the provinces is 0.45; only 12 provinces are higher than the average level, which accounts for 40% of all provinces.

Low-carbon development in the 30 provinces is generally high, but the gap between the highest-scoring provinces and the lowest-scoring provinces is relatively large because of their different geographical features. The highest-scoring area is Beijing, with an index of 0.98, and the lowest is Ningxia, with an index of 0.27. Most cities' low-carbon development level is higher than the average urbanization level, which indicates that low-carbon development has a leading role in urbanization.

To further develop China's low-carbon urbanization, in addition to strengthening policy design and the control of carbon emission intensity in the carbon emission management system, attention should be paid to the CO_2 emissions *per capita*. In the process of urbanization, the quality of public social service should be improved, and medical coverage for seniors should be expanded. In addition, there is a need to improve community service coverage in infrastructures, to strengthen resource optimization and environmental protection, and especially to improve the green design in urban construction.

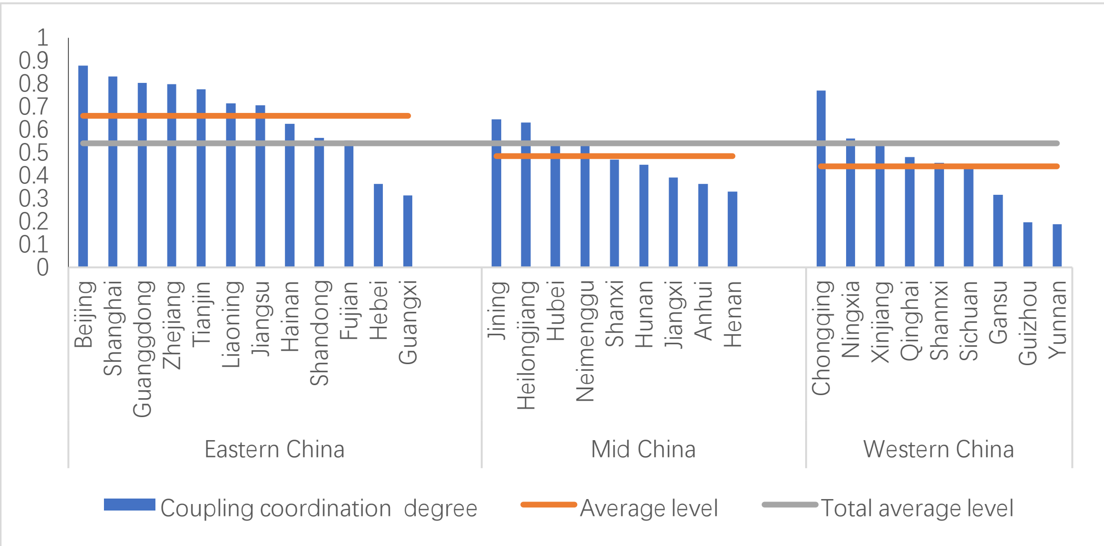

Figure 10. The coupling coordination development in different regions

The coordination of low-carbon development and new urbanization in a provence is closely related to its developmental stage and geographic location. China’s eastern provinces have the highest degree of coordinated development; western provinces are at the lowest degree of coordinated development. The reason is that urbanization levels of western provinces are lower, but the dependence of economic development on energy consumption is higher. In addition, the level of coupling coordination in the eastern provinces and western provinces, compared to provinces in the same region, is different, which indicates that the two regions of the provinces in the low-carbon development have significant gaps between the urbanization and low-carbon development. Therefore, more attention shoud not only be paid to the middle east and west provinces located in different stages of development and geographical location, but also to explore and study the convergence and differences in the construction of low-carbon urbanization in different provinces of the same region.

For provinces with different degrees of coupling coordination in the low-carbon development - new urbanization system , there is a need to explore in different developmental directions. Since most low-carbon-low-urbanization provinces, such as Guizhou and Gansu, are located in western regions, their economic development and urbanization processes are over-reliant on energy consumption. Sufficient funds and policy support in resource and environment optimization are also in shortage in these provinces, thus causing an extreme lack of coordination between low-carbon development the new urbanization system. This is an unsustainable development process, indicating an urgent need to change. For these provinces, the promotion of economic development still plays a dominant role. Therefore, to promote economic growth, refine economic restructuring, lay a sound foundation for economic growth, and to contribute to low-carbon development, it is necessary to construct "low-carbon supporting industries" based on the specific needs of the province. The low- and medium-carbon urbanization provinces, such as Shandong and Hubei, are currently undergoing low-carbon development and new urbanization, and the economic structure is already under transformation. For these provinces, the bottleneck of economic development through industrial restructuring need to be broken. Meanwhile, in addition to improving the quality of public services and infrastructure construction, the carrying capacity of resources and environment is also important to avoid high-development–low-coordination. On the other hand, low-carbon-high-urbanization provinces, such as Tianjin and Liaoning, will have to drive low-carbon development through urbanization in the future. For high-low carbon-low urbanization provinces, such as Anhui and Jiangxi, their future focus on construction shouldbe improving the quality of urbanization and strengthening public services, infrastructure construction, and environmental resources protection. The provinces with high and low carbon-high urbanization, such as Beijing and Guangdong, are more economically developed and are more coordinated in addressing the relationship between new urbanization and low-carbon development. Under the circumstances of developed economy, there are sufficient funds to improve the quality of urbanization with basic public services and infrastructure construction, but then the carrying capacity of resources and environment in the process of urbanization becomes an issue,to reduce the dependence on carbon emissions to get a sustainable development model.

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