Conflict or coordination? Assessment of coordinated development between socioeconomic and ecological environment in resource-based cities: evidence from Sichuan province of China

Yi Xiao 1 · Yuan Li 2 · Huan Huang 3

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Abstract

The relationship between socioeconomic and ecological environment becomes a significant factor influencing the regional sustainable development of resource-based cities (RBCs); how to coordinate the relationship between socioeconomic growth and ecological environment is the key problem to achieve sustainable development goals of RBCs. A comprehensive evaluation indicator system was constructed to research the coupling coordination level of RBCs in this paper; the dynamic DM model and the CCD model were adopted to measure the comprehensive level of the coupling coordination degree between socioeconomic and ecological environment of the 9 resource-based cities from 2008 to 2018 in Sichuan province. The results showed that the coupling coordination level was not ideal. Only two cities were located to the moderate coordination, and other cities were located to the primary coordination or tiny coordination. In addition, there was a significant difference between SE and EE, and the comprehensive evaluation score of SE was lower than that of EE in eight RBCs, which accounts for 88.89%. Based on this, we analyzed the reasons for the backward development of the socioeconomic system of the resource-based cities in order to provide relevant references for the transformation of the RBCs. Finally, the policy suggestions for the sustainable development of different types of RBCs were provided, involving improving the policy and financial support for enterprise transformation, promoting high-new technology to improve production efficiency, strengthening government guidance on industrial layout, stabilizing employment, and improving the social security system. This study offers a model of China’s experience that might be beneficial for achieving sustainable development goals (SGDs) of other cities and countries.

Keywords Socioeconomic · Ecological environment · Resource-based cities · Sichuan province · Coupling coordination degree

Introduction

Resource-based cities (RBCs) are the core elements to promote the industrialization process in China. In general, the RBCs are cities that have enrichment energy resources, and the exploitation of energy or mineral resources is the core driving force for urban economic growth. However, due to the serious pollution caused by the exploitation of energy resources and the characteristics of non-renewable resources, the RBCs are faced with the challenge of how to take the road of green development. Statistical studies show that RBCs have the phenomenon of “resource curse,” which means that the degree of resource abundance is inversely proportional to the level of sustainable economic growth (Yang and Song 2019; Manzano and Gutiérrez 2019; Zhang and Cui 2020). The economic growth rate of resource-based cities usually changes from high to low in the rapid development of resource-based enterprises, but the ecological environment mostly shows the
condition of gradual deterioration (Poncian 2019; Adams et al. 2019). Breaking the traditional development mode and exploring a growth path that conforms to the coordinated development of socioeconomic and ecological environment has become a core issue for the transformation of RBCs.

The number of resource-based cities accounts for more than one-third of all Chinese cities (The State Council of China, 2013). These cities have made significant contributions to China’s industrialization path and economic growth. However, there are many environment and social problems caused by the exploitation of natural resources, such as industrial waste water pollution, mine vegetation destruction, and mining area unemployment. As a resource-dependent city, the economic growth and social development of RBCs mainly depend on resource output, which presents an obvious phenomenon of “resource curse,” and the long-term extensive economic growth model seriously restricts the industrial transformation and ecological environment optimization of RBCs (Zhang and Cui 2020; Frynas and Buur 2020). China’s high-quality development model puts higher standard for urban economic growth and industrial transformation, and the sustainable development ability of RBCs that rely on traditional natural resources has become the focus of urban transformation (Huang et al. 2020b; Hu et al. 2020). The successful transformation and development of resource-based cities is one of the important characteristics for Chinese cities to achieve high-quality development goals, while resource-based cities in economically underdeveloped regions are facing greater pressure of urban transformation such as Sichuan province in western regions of China (Xie et al., 2020a, b; Li et al., 2021a, b). To realize the transformation and sustainable development goals of RBCs, the relationship between socioeconomic and ecological environment should be coordinated.

Based on the National Sustainable Development Plan of RBCs, there are four types of RBCs, involving resource-growth cities, resource-mature cities, resource-depleted cities, and resource-regeneration cities (The Central people’s Government of the People’s Republic of China, 2013). This paper adopts the above classification to research the coupling coordination degree (CCD) between socioeconomic (SE) and ecological environment (EE) of nine RBCs in Sichuan province of China. Through the selection of evaluation model and construction of the theoretical framework (Fig. 1), the indicator system of CCD between SE and EE is determined. By comparing evaluation results of four types of cities, the key factors affecting different types of RBCs can be found out. In addition, it is worth noting that RBCs of China have significant similarities in their development paths and transformation modes, and the successful transformation experience of a single city can be quickly promoted to other cities. Therefore, the research on the four types of cities in Sichuan province is highly applicable to RBCs in other regions of China.

Based on previous studies on RBCs, the dynamic deviation maximization method and coupling coordination degree model are used to conduct empirical research (Fang et al., 2016; Li et al., 2020a, b, c, d). This paper conducts case studies on the development paths of different types of RBCs in Sichuan province and discusses the CCD between SE and EE of RBCs in western China. Among them, the resource-mature cities and resource-depleted cities are the key points of urban transformation and sustainable development, which account for the highest proportion in China. The industries and economies of these cities are under pressure to transform. Therefore, the dilemma faced by RBCs in different periods is summarized to provide reference for achieving the sustainable development goals (SDGs) of different types of RBCs.

**Literature review**

The socioeconomic development of RBCs mainly depends on the natural resource exploitation, and the traditional economic

![Fig. 1 Theoretical model proposed.](image)
growth model has caused tremendous pressure to the urban nature environment, including excessive urban sewage discharge, acid rain, air pollution, and soil pollution. Coordinating the relationship between SE and EE has become a core issue to industrial transformation of RBCs (Xing et al., 2019; Liu et al., 2020a, b). Existing researches on sustainable development of RBCs are mainly carried out from three aspects: (1) urban innovation efficiency. The innovation of science and technology is the key factor of the transformation of RBCs (Lv et al., 2019), and the improvement of innovation efficiency mainly depends on the support of high-tech industry and government policy (Yang and Na, 2019; Tie et al., 2020). (2) The second is urban industrial transformation model and green transformation performance. Optimizing the industrial structure and strengthening technology investment in extensive enterprise of RBCs are the two main models to achieve industrial transformation (Kuai et al., 2015; Zhang et al., 2018; Xie et al., 2020). Besides, the industrial optimization policies promulgated and implemented by the Chinese government are also conducive to the improvement of the ecological environment of RBCs (Ruan et al., 2020; Li et al., 2021a, b). (3) The third is ecological vulnerability and ecological security of RBCs. The long-term mining of mines will pose tremendous pressure to the urban ecological security and ecological vulnerability degree of RBCs, which is difficult in realizing urban and industrial transformation in RBCs (Chen et al., 2019; He et al., 2019; Yang et al., 2020a, b; Dai et al., 2020).

The existing literature on the coupling relationship between economic development and ecological environment mainly focuses on cities and different regions, especially on the coupling and coordination relationship between economic development and ecological environment in economically underdeveloped cities (Liu et al., 2020a, b; Yang et al., 2020; Xiao et al., 2021; Li et al., 2021a, b). There are also studies on economically developed areas (Cui et al., 2019; Sun and Shen, 2020). Besides, there are also some studies to analyze the characteristics of coordinated evolution between economic development and ecological environment from the perspective of provinces and carried out empirical analysis on the spatial characteristics and spatial relations of different regions (Liu et al., 2019; Shi et al., 2020; Huang et al., 2020).

From what has been discussed above, there are abundant studies on coupling between economic growth and ecological environment, but it is lacking of researching on the coordination between socioeconomic and ecological environment of different types of RBCs. For one thing, the ecological footprint model and the CDI are introduced to assess the comprehensive score of socioeconomic and ecological environment from the macro and meso perspective (Yang and Na 2019; Xu et al., 2019; Ariken et al., 2020); by measuring the comprehensive index of SE and EE between different regions, the harmonious relationship of sustainable development between regions and within regions is analyzed, which also verifies the existence of environmental Kuznets curve (Li et al., 2016a, b; Pontarollo and Serpieri, 2020; Peng et al., 2020). For another, some studies have segmented economic development and researched the coupling and coordinated evolution of urban ecological environment from the perspectives of urban urbanization, land use, and urban tourism development (Tang, 2015; Chai et al., 2017; Kurniawan et al., 2019; Wang et al., 2019; Yang et al., 2020).

The CCD refers to the measurement of the coordination relationship between two or more dynamically changing systems (Fu et al., 2020). Presently, many methods have been excavated to calculate the comprehensive index and the dynamic change rule of coordination relationship between SE and EE. Conventional evaluation methods mainly include the system dynamics model (Derwisch and Loewe, 2015; Elswah et al., 2017; Li et al., 2020a, b, c, d), grey relational analysis model (Wang et al., 2010; Li et al., 2012; Yang and Wu, 2019), fuzzy comprehensive evaluation method (Zeng and Feng, 2013; Xu and Li, 2019; Wen et al., 2021), the CCD model (Xu et al., 2019; Tao et al., 2020; Yang et al., 2020; Gan et al., 2020), the principal component analysis method (Fan et al., 2017; Li et al., 2020a, b, c, d), the support vector machine method (Zhao and Lam, 2012; Zhao and Jin, 2018), etc. Among them, the system dynamics model is mainly used for system simulation and evaluation in energy field (Guo et al., 2020). Grey relational analysis model and fuzzy comprehensive evaluation method are mainly used for assessment of single system comprehensive change, which cannot reflect the coordinated development between multiple systems (Sun et al., 2018; Zhang et al., 2021). When the principal component analysis method is used for evaluation, the correlation between indicators can be eliminated, but the extracted principal components are likely to produce a large information gap with the reality, which will lead to the deviation between the evaluation results and the reality (Forkman et al., 2019). The support vector machine method can simultaneously deal with multiple related indicators and predictions, but it cannot dynamically evaluate the coordination relationship between multiple systems (Ju et al., 2019).

Most of these methods can only evaluate and simulate a single system, and cannot estimate the mutual-changing relationship between two or more systems; the CCD model (CCDM) is the most widely used method to estimate the variation of coupling coordination of multiple systems. By identifying the information difference between the indicators, the dynamic deviation maximization model can make the combined weight vector to maximize the deviation and can calculate the optimal solution of the comprehensive system (Xiao et al., 2021). Therefore, the dynamic deviation maximization model and the CCDM are combined to measure the comprehensive coordination level of RBCs in Sichuan province in this paper.
Consistent with diversified application of evaluation methods, there is no consensus on the indicator system of coupling, and coordination evaluation of socioeconomic and ecological environment has not been unified. For one thing, the socioeconomic evaluation of RBCs mainly involves economic growth (Li and Zhou, 2020), industrial structure (Tan et al., 2020), social employment (Tan et al., 2016), education level and medical care (Li and Dewan, 2017), etc. For another, the ecological environment evaluation of RBCs includes ecological endowment (He et al., 2019), ecological environment pressure (Song et al., 2020), the environmental protection, and pollution control (Wu et al., 2020). Therefore, both SE subsystem and EE subsystem contain many aspects of content. However, most of the existing researches on RBCs focus on the evaluation of a single city (Li et al., 2016a, b; He et al., 2019; Wang et al., 2020), and it is lacking of researching on dynamic assessment of the coordinated development of two or more systems of RBCs.

Because most resource-based cities in China are facing giant pressure of social and economic transformation, how to explore the common problems in the development of different types of resource-based cities is the key to achieve the sustainable development goals (Li et al., 2021a, b; Huang et al., 2020a, b; Yang et al., 2021). Most of the existing researches focus on a single resource-based city and lack of empirical analysis of the development experience on different types of resource-based cities. Therefore, this paper selected 9 RBCs in Sichuan province as example for research; it is expected to provide an experience reference for urban transformation or regional sustainable development in underdeveloped areas.

**Study area**

According to the National Sustainable Development Plan for RBCs (2013–2020), there are 262 RBCs at the prefecture-level, county-level, and municipal districts involved in the plan (State Council, 2013). And there are 102 RBCs in the western China, which accounts for 38.93%. The disequilibrium contradiction between socioeconomic and ecological environment is more significant due to the large area and the economically underdeveloped regions of western China. For instance, the western region accounts for 20.71% of China’s GDP in 2019, which is at a relatively low level. In addition, there are 9 prefecture-level RBCs in Sichuan province, which accounts for 42.86%. The basic general situation of nine resource-based cities in Sichuan province is illustrated in Table 1.

| City      | Population | Area (Km²) | Per capita (Yuan) | Main resources                                      |
|-----------|------------|------------|-------------------|-----------------------------------------------------|
| Nanchong  | 7,237,100  | 12,477     | 36,073            | Oil, gas, gold, iron, uranium, phosphorus, salt     |
| Zigong    | 3,203,500  | 4,381      | 48,904            | Coal, salt, gas                                     |
| Panzhihua | 1,083,700  | 7,401      | 82,500            | Iron, vanadium, coal, chromium, gallium, scandium, nickel, copper |
| Guangyuan | 2,988,600  | 16,311     | 35,262            | Coal, gold, silicon, graphite                       |
| Guangan   | 4,593,000  | 6,341      | 38,522            | Coal, gas, oil, iron, salt                          |
| Dazhou    | 6,589,400  | 16,582     | 30,982            | Coal, gas, iron, vanadium, salt                     |
| Yaan      | 1,541,000  | 15,046     | 46,984            | Coal, gas, iron, cobalt, manganese, titanium         |
| Luzhou    | 5,085,400  | 12,236     | 48,105            | Coal, oil, gas, iron, copper, gold                  |
| Aba       | 899,300    | 83,016     | 41,278            | Gold, lithium, iron, shale mine, coal                |

**Methods**

**Construction of comprehensive index system**

The indicator system is established to scientifically reflect the comprehensive evaluation score of regional SE and EE subsystem in different perspectives. The selection of each indicator must abide by the principles of objectivity, scientific, comprehensive, and accessibility. By referring to existing literature and considering the availability of research data, the indicator system established in this paper is shown in Table 2.
The SE subsystem contains three primary indicators and eleven second-level indicators. The indicators “Per capita GDP,” “Per capita disposable income of urban residents,” “Per capita retail sales of consumer goods,” and “Per capita export trade” were selected to reflect the urban economic growth and urban economic comprehensive level. The indicators “Proportion of secondary industry to GDP” and “Proportion of service industry to GDP” were used to reflect the dynamic changes of urban industrial structure. The indicator “Unemployment rate,” “Urbanization rate,” “Natural

Table 2  The indicator system of socioeconomic and ecological environment

| Subsystem                                      | Primary indicators                        | Secondary indicators                                      | Unit         | Weight |
|------------------------------------------------|-------------------------------------------|-----------------------------------------------------------|--------------|--------|
| Socioeconomic subsystem                        | Economic growth                           | Real per capita GDP                                        | Yuan         | 0.198  |
|                                                |                                            | Per capita disposable income of urban residents            | Yuan         | 0.097  |
|                                                |                                            | Per capita retail sales of consumer goods                  | Yuan         | 0.065  |
|                                                |                                            | Per capita export trade                                    | Yuan         | 0.033  |
|                                                |                                            | Industrial structure                                       | %            | 0.114  |
|                                                |                                            | Proportion of secondary industry to GDP                    | %            | 0.128  |
| Social development                             |                                            | Unemployment rate                                          | %            | 0.105  |
|                                                |                                            | Urbanization rate                                          | %            | 0.061  |
|                                                |                                            | Natural population growth rate                             | %            | 0.041  |
|                                                |                                            | Proportion of educational expenditure to the public finance| %            | 0.092  |
|                                                |                                            | Number of doctors per 10,000 people                       | 10,000       | 0.066  |
| Ecological environment subsystem                | Ecological endowment                      | Forest coverage rate                                       | %            | 0.027  |
|                                                |                                            | Per capita green area                                      | m²           | 0.027  |
|                                                |                                            | Green coverage rate in built-up areas                     | %            | 0.059  |
|                                                |                                            | Per capita arable land                                    | m²           | 0.041  |
|                                                |                                            | Ecological environment pressure                            | tons         | 0.264  |
|                                                |                                            | Per capita discharged volume of industrial waste water    | tons         | 0.138  |
|                                                |                                            | Per capita discharged volume of industrial SO₂            | tons         | 0.157  |
| Environmental protection and pollution control  |                                            | Sewage treatment rate                                     | %            | 0.175  |
|                                                |                                            | Harmless disposal rate of household garbage                | %            | 0.081  |
|                                                |                                            | Comprehensive utilization rate of industrial solid waste   | %            | 0.031  |
population growth rate,” “Proportion of educational expenditure to the public finance,” and “Number of doctors per 10,000 people” were selected to reflect the comprehensive score of employment, population growth, education development, and medical health services.

The EE subsystem includes three primary indicators and ten secondary indicators. This paper selected the four indicators “Forest coverage rate,” “Per capita green area,” “Green coverage rate in built-up areas,” and “Per capita arable land” to represent the regional ecological endowment. The indicators “Per capita discharged volume of industrial waste water,” “Per capita discharged volume of industrial SO2,” and “Per capita discharged volume of industrial dust” were used to measure the pollution pressure caused by industrial development to the ecological environment. Intensity of environmental regulation is an important guarantee for the quality of regional ecological environment. Therefore, the indicators “Sewage treatment rate,” “Harmless disposal rate of household garbage,” and “Comprehensive utilization rate of industrial solid waste” were used to explain the capability of environmental protection and governance.

It is noted that the secondary indicators demonstrated above cannot absolutely explain the comprehensive level in SE and EE of RBCs. For instance, the utilization rate of renewable energy, the utilization rate of non-renewable energy, and the proportion of the output value of high-tech industries are important factors to measure the comprehensive sustainable development of RBCs. However, due to the unavailability of statistical data for some years of the study area. There, these indicators are not included in this paper.

### The dynamic deviation maximization method

In order to eliminate the effect of unit differences of indicator variables, the original indicator variable \( R_{ij}^k \) needs to be standardized, and \( R_{ij}^k \) refers to the assessment period \( t_k \) of city \( o_i \) on indicator \( I_j \), where \( i = 1, 2, \cdots, n \), \( j = 1, 2, \cdots, m \), \( k = 1, 2, \cdots, N \). Formula (1) was used to standardize the positive indicators, and Formula (2) was used to standardize the negative indicators.

\[
Q_{ij}^k = \frac{R_{ij}^k - \min \left( R_{ij}^k \right)}{\max \left( R_{ij}^k \right) - \min \left( R_{ij}^k \right)}
\]

\[
Q_{ij}^k = \frac{\max \left( R_{ij}^k \right) - R_{ij}^k}{\max \left( R_{ij}^k \right) - \min \left( R_{ij}^k \right)}
\]

where \( Q_{ij}^k \) represents the standardized matrix and \( \max \left( Q_{ij}^k \right) \) and \( \min \left( Q_{ij}^k \right) \) represent the maximum value and the minimum value in the original matrix of indicator \( I_j \), respectively.

The calculation steps of indicator weight are as follows:

\[
\delta_i = \frac{\sigma_i}{Q_i} = \frac{\sum_{j=1}^{m} Q_{ij}}{m} \tag{3}
\]

\[
\sigma_i = \sqrt{\frac{\sum_{j=1}^{m} \left( Q_{ij} - \bar{Q}_i \right)^2}{m}}
\]

Set the coefficient of variation of each indicator as \( \delta_i, 1 \leq \delta_i \leq N \). The corresponding weight of the coefficient of variation was obtained by normalizing the coefficient of variation of each indicator.

\[
w_i = \frac{\delta_i}{\sum_{i=1}^{N} \delta_i} \tag{4}
\]

\[w = (w_1, w_2, \cdots, w_m)^T\] represents the undetermined weights of \( m \) indicators. The weighted sum model (5) was adopted to assemble the standardized indicator values and the indicator weights.

\[
Z_{i}^{tk} = \sum_{j=1}^{m} Q_{ij}^k w_j, i = 1, 2, \cdots, n
\]

where \( Z_{i}^{tk} \) represents the comprehensive evaluation score of cities \( o_i \) in the period \( t_k \).

The dynamic DM model was used for the purpose of assigning scientific weights to indicator variables; it can maximize the overall difference of decision scheme for each period, and the optimal decision scheme can be realized. Based on this, the programming model (6a) and (6b) were used to make decisions.

\[
\max \sum_{k=1}^{N} \sum_{i=1}^{n} \left( Z_{i}^{tk} - \bar{Z} \right)^2 \tag{6a}
\]

s.t. \[\begin{align*}
W^T W &= 1 \\
0 &\leq w_j \leq 1
\end{align*}\] (6b)

where \( \bar{Z} \) is the average score of each evaluation results of all decision schemes and \( \bar{Z} \) is calculated by Formula (7).

\[
\bar{Z} = \frac{1}{N} \sum_{k=1}^{N} \left( \frac{1}{n} \sum_{i=1}^{n} Z_{i}^{tk} \right)
\]

(7)

The constraint condition \( W^T W = 1 \) will cause the sum of each indicator weights not equal to 1 in the programming model (6a) and (6b). So, the final weight of each indicator was calculated by standardization treatment, and \( w_j = w_j / \sum_{j=1}^{m} w_j \), where \( w_j \) was calculated by the model (6a) and (6b), and the final weight of each indicator were showed in Table 2.
CCD model

The variables $Z_{SE}$ and $Z_{EE}$ refer to the comprehensive evaluation score of SE and EE subsystem, respectively. The calculation process of CCD was as follows:

$$C = \frac{\sqrt{Z_{SE} \times Z_{EE}}}{(Z_{SE} + Z_{EE})/2}$$  \hspace{1cm} (8)

$$T = \alpha Z_{SE} + \beta Z_{EE}$$  \hspace{1cm} (9)

$$CCD = \sqrt{C \times T}$$  \hspace{1cm} (10)

where $C$ represents the coupling level of SE and EE, $T$ refers to the evaluation scores of SE and EE, and $\alpha$ and $\beta$ are undetermined coefficients of SE and EE, with $\alpha + \beta = 1$ and $\alpha, \beta \in [0, 1]$. In general, socioeconomic development is important as the ecological environment under urban sustainable development goals. Therefore, the value of $\alpha$ and $\beta$ is the same in this paper, $\alpha = \beta = 0.5$.

The variable CCD refers to the comprehensive evaluation score of coupling coordination of RBCs, and the value range is (0, 1). The higher the evaluation value of CCD indicates that the higher the coupling coordination score and the higher the SE and EE comprehensive evaluation scores of research region. Conversely, the lower the evaluation value of CCD indicates that the lower the evaluation level. And there is no coupling coordination degree when the value of CCD is 0; this is in contradiction with the development of urban reality (Yang and Na, 2019; Li et al., 2020b, c).

Results and findings

Analysis of evaluation results of SE

The comprehensive evaluation results of SE in the 9 RBCs of Sichuan province showed significant differences (see the results shown in Table 3). From 2008 to 2018, the comprehensive level of the SE in Sichuan province presented an escalating trend, from 0.305 to 0.391, with an increase of 28.20%. However, the growth rate and growth range of the RBCs in Sichuan province were different, with significant spatial differences. In addition, it can be found that there are significant differences in SE levels among the mature type of RBCs.

It is shown that Panzhihua had the highest evaluation score and Nanchong had the lowest evaluation score in socioeconomic development. The evaluation scores of Nanchong increased from 0.138 to 0.206 during this period, and Nanchong is a resource-growth city with abundant mineral resources. The driving force of socioeconomic development in Nanchong is the heavy exploration of oil, gas, iron, etc. As the oil and gas and energy chemical industry base in Sichuan province of western China, with the large-scale exploitation of natural resources, the SE of Nanchong has been rapidly promoted.

There are 6 prefecture-level resource-mature cities in Sichuan province. It is shown that the growth difference of SE in these cities is relatively significant. The evaluation scores of Zigong, Panzhihua, Guangyuan, Guangan, and Dazhou showed an upward trend, and the evaluation scores increased from 2008 to 2018 were 10.87%, 0.56%, 63.64%, 16.22%, and 42.16%, respectively. As one of the four major iron mining areas in China, the resource reserves of associated titanium in Panzhihua accounted for 93% of the country. From 2008 to 2018, the evaluation score increased from 0.784 to 0.788 in Panzhihua, which has the best comprehensive evaluation score in SE among the RBCs in Sichuan province. Guangyuan, Guangan, and Dazhou lie in the northeast of Sichuan province, due to the long-term dependence on traditional mining and heavy industry, which leads to the relatively backward social and economic development. Although Northeast Sichuan is an important energy base in western China, industrial development has not brought significant social progress and development, and the evaluation scores in these cities were lower than other cities in Sichuan province.

The evaluation scores of Luzhou increased from 0.264 to 0.413 during the time, and Luzhou is a resource-depleted city.
in Sichuan province. It can be seen from the calculation results that the socioeconomic development of Luzhou grew rapidly from 2016 to 2018, indicating that Luzhou is undergoing urban industrial transformation to promote the urban high-quality sustainable development. The evaluation scores of Aba decreased from 0.273 to 0.253, with a decrease of −7.33%, and Aba is a resource-regeneration city in Sichuan province. Tourism industry is gradually displacing the dominant role of extractive industries, and it takes the highest proportion.

**Analysis of evaluation results of EE**

It is shown that the comprehensive evaluation score of EE in the 9 resource-based cities of Sichuan province presented an increasing trend (Table 4), from 0.455 to 0.521, with an increase of 14.51%. It can be found that depletion city has the lowest EE evaluation score, and regeneration city has the highest EE evaluation score of RBCs in Sichuan Province. In addition, the scores of growth type and mature type fluctuate significantly, because these two types of resource-based cities have the greatest intensity of resource exploitation and tend to ignore environmental protection and pollution control in the process of resource exploitation.

The EE evaluation score of Aba increases from 0.305 in 2008 to 0.391 in 2018, with an increase of 26.12%, and the evaluation score of Aba is higher than that of other RBCs in Sichuan province; the main reason is that Aba is a resource-regeneration city, and its industrial development direction has changed to the tertiary industry, which has strengthened the environmental regulation. Luzhou is the only city with a decline trend in EE score in Sichuan province; the EE evaluation score of Luzhou decreases from 0.449 in 2008 to 0.402 in 2018, with a decrease of −10.47%; due to the industrial structure dominated by extractive industry for a long time, the pressure on ecological environment has increased, which leads to some serious social or environment problems such as excess energy, resource depletion, and ecological environmental pollution.

The ecological environment score of resource-mature cities is better than that of resource-growth and resource-depleted cities in Sichuan province from 2008 to 2018. The evaluation score of EE in Nanchong, Zigong, Panzhihua, Guangyuan, Guangan, Dazhou, and Yaan showed an increase trend of fluctuating; the respective increases from 2008 to 2018 were 35.90%, 24.22%, 10.81%, 10.17%, 23.06%, 1.38%, and 16.83%; the main reason is that the intensity of environmental regulation has been gradually strengthened in recent years, which has alleviated the ecological environmental pollution caused by the vigorous development of the extractive industry and heavy industry to some extent. However, it is shown that the evaluation results in EE scores of resource-mature cities and resource-growth cities showed a trend of decline in many years; the main reason is that some cities have not implemented environmental regulation policies and the local government has not provided support for the ecological environment protection of large-scale mining areas.

**Findings of evaluation results of CCD**

The dynamic changes of the CCD of the 9 resource-based cities are shown in Fig. 3. The results showed that the comprehensive evaluation level of the CCD in the 9 resource-based cities in Sichuan province showed an upward trend (Table 5), from 0.541 to 0.584, with an increase of 7.95%. There are eight cities that had the CCD evaluation scores below 0.6 in 2008, and eight cities had the CCD evaluation scores below 0.7 in 2018; it indicates that the coordination degree between SE and EE is relatively low in the resource-based cities of Sichuan province.

The CCD evaluation score of Panzhihua increase from 0.724 in 2008 to 0.757 in 2018, with an increase of 4.56%, and the evaluation score of Panzhihua is higher than that of other cities; the main reason are as follows. The development of the extractive industry in Panzhihua is an important force to promote the industrialization of western China. It is rich in

| City type | Year | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|-----------|------|------|------|------|------|------|------|------|------|------|------|------|
| Growth    |      |      |      |      |      |      |      |      |      |      |      |      |
| Nanchong  | 0.312| 0.297| 0.265| 0.259| 0.290| 0.308| 0.357| 0.348| 0.416| 0.402| 0.424|      |
| Zigong    | 0.351| 0.333| 0.313| 0.305| 0.342| 0.363| 0.368| 0.359| 0.378| 0.401| 0.436|      |
| Panzhihua | 0.444| 0.389| 0.375| 0.343| 0.384| 0.436| 0.452| 0.476| 0.482| 0.490| 0.492|      |
| Guangyuan | 0.541| 0.598| 0.572| 0.611| 0.564| 0.567| 0.560| 0.571| 0.577| 0.584| 0.596|      |
| Guangan   | 0.464| 0.440| 0.525| 0.520| 0.504| 0.516| 0.524| 0.511| 0.536| 0.559| 0.571|      |
| Dazhou    | 0.506| 0.507| 0.489| 0.525| 0.492| 0.498| 0.507| 0.516| 0.510| 0.499| 0.513|      |
| Yaan      | 0.517| 0.498| 0.503| 0.527| 0.540| 0.556| 0.585| 0.587| 0.573| 0.584| 0.604|      |
| Depletion |      |      |      |      |      |      |      |      |      |      |      |      |
| Luzhou    | 0.449| 0.374| 0.341| 0.351| 0.369| 0.370| 0.394| 0.377| 0.390| 0.370| 0.402|      |
| Regeneration |      |      |      |      |      |      |      |      |      |      |      |      |
| Aba       | 0.513| 0.569| 0.592| 0.597| 0.603| 0.601| 0.615| 0.624| 0.640| 0.639| 0.647|      |
| The region| 0.455| 0.445| 0.442| 0.449| 0.454| 0.468| 0.485| 0.485| 0.500| 0.503| 0.521|      |
natural resources such as coal, steel, and vanadium and titanium, and it has the highest per capita GDP in Sichuan province. The comprehensive evaluation score of the CCD in the resourced-based cities of Sichuan province was not ideal.

The CCD comprehensive level of RBCs in Sichuan province was divided into five grades in this paper, as shown in Fig. 4. The level I represents good coordination with the CCD value range of (0.8, 0.9). In the level II, the value range of CCD is (0.7, 0.8), indicating the moderate coordination. The value range of CCD in the evaluation city is (0.6, 0.7), which indicates primary coordination. It is divided into the level IV when the CCD value of the evaluation city is [0.5, 0.6), indicating tiny coordination. The level V represents the mild dissonance with the CCD value range of (0.4, 0.5).

It is shown that there is no city in level I and level III in 2008, and only one city located to the level of moderate coordination; five RBCs are located to the level of tiny coordination, accounting for 55.56%. Besides, there are three cities located to the level of mild dissonance. In terms of 2018, the results showed that there is no city in level I, and the number of cities with primary coordination increased from zero in 2008 to two in 2018, and the number of cities with mild dissonance decreased from three in 2008 to one in 2018. Besides, the number of cities with tiny coordination remained unchanged overall from 2008 to 2018. It indicates that there is an unbalanced development level in SE and EE of the 9 RBCs in Sichuan province. Although some RBCs were located to the coordination level, the coordination degree showed decline trend in some year. The main reason is that the comprehensive evaluation level of SE in most RBCs was far behind that of EE in Sichuan province, this can be seen from Table 3 and Table 4, and it can also be more clearly seen from Table 6.

Table 6 showed that there were three cities that had smaller gap of the two subsystems in Sichuan province, involving Nanchong, Zigong, and Luzhou. From the average level of the results, it is shown that only the SE of Panzhihua was better than EE. For the other eight RBCs, their evaluation level of CCD was lower than that of EE, which accounts for 88.89%. It is noted that there was a significant difference between SE and EE in Panzhihua, Dazhou, and Guangyuan, with their absolute deviation value above 0.3. For one thing, from the perspective of SE growth rate, there were four cities that had the growth rate of more than 20%, including Nanchong, Guangyuan, Dazhou, and Luzhou. And it showed

| City type     | Year     | 2008  | 2009  | 2010  | 2011  | 2012  | 2013  | 2014  | 2015  | 2016  | 2017  | 2018  |
|--------------|---------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Growth       | Nanchong| 0.404 | 0.393 | 0.431 | 0.413 | 0.422 | 0.431 | 0.441 | 0.447 | 0.492 | 0.472 | 0.506 |
|              | Zigong  | 0.579 | 0.569 | 0.570 | 0.563 | 0.574 | 0.588 | 0.579 | 0.578 | 0.600 | 0.576 | 0.623 |
|              | Panzhihua| 0.724 | 0.679 | 0.667 | 0.636 | 0.675 | 0.716 | 0.728 | 0.744 | 0.747 | 0.753 | 0.757 |
|              | Guangyuan| 0.444 | 0.563 | 0.553 | 0.532 | 0.534 | 0.547 | 0.547 | 0.556 | 0.571 | 0.574 | 0.584 |
|              | Guangan | 0.553 | 0.557 | 0.568 | 0.531 | 0.547 | 0.560 | 0.550 | 0.599 | 0.625 | 0.616 | 0.597 |
|              | Dazhou  | 0.461 | 0.451 | 0.448 | 0.402 | 0.416 | 0.425 | 0.429 | 0.461 | 0.572 | 0.570 | 0.558 |
|              | Yaan    | 0.576 | 0.589 | 0.603 | 0.593 | 0.604 | 0.578 | 0.552 | 0.571 | 0.575 | 0.596 | 0.562 |
| Depletion    | Luzhou  | 0.557 | 0.570 | 0.573 | 0.573 | 0.592 | 0.598 | 0.596 | 0.591 | 0.632 | 0.636 | 0.638 |
| Regeneration | Aba     | 0.568 | 0.621 | 0.683 | 0.659 | 0.683 | 0.662 | 0.645 | 0.676 | 0.711 | 0.564 | 0.542 |
| The region   |         | 0.541 | 0.555 | 0.566 | 0.545 | 0.561 | 0.567 | 0.563 | 0.580 | 0.614 | 0.571 | 0.584 |
that there was a significant difference of the SE growth rate between RBCs in Sichuan province. For another, from the perspective of EE growth rate, there were four cities that had the growth rate of more than 20%, involving Nanchong, Zigong, Guangan, and Aba; Luzhou was the only city with the negative growth rate.

The reason for the backward development of SE lies in the unbalanced development of regional economy and the single industrial structure. The economic growth of these cities depends on the development of long-term extractive industries and heavy industries. However, due to these industries put increasing pressure on the ecological environment, which leads to more serious contradictions between SE and EE. In addition, the problem of overcapacity in these cities is prominent under the high-quality development, which leads to some serious social problems, such as the rise of social unemployment rate, unstable income of residents, burden of the government’s social security expenditure, etc. By analyzing the initial values of each indicator, it is found that the loss of labor force and the slow growth rate of population were the two important factors affecting the lagging development of SE.

Table 6 The growth rate and difference in SE and EE of the 9 RBCs in Sichuan province of China.

| City      | M-SE* | M-EE* | Difference* | SE growth rate (%) | EE growth rate (%) |
|-----------|-------|-------|-------------|-------------------|-------------------|
| Nanchong  | 0.166 | 0.334 | 0.169       | 56.11             | 35.97             |
| Zigong    | 0.326 | 0.359 | 0.033       | 10.82             | 24.09             |
| Panzhihua | 0.760 | 0.433 | 0.327       | 0.56              | 10.72             |
| Guangyuan | 0.254 | 0.576 | 0.322       | 63.35             | 10.13             |
| Guangan   | 0.279 | 0.515 | 0.236       | 16.4              | 23.06             |
| Dazhou    | 0.198 | 0.506 | 0.308       | 42.31             | 1.31              |
| Yaan      | 0.287 | 0.552 | 0.265       | −4.64             | 16.72             |
| Luzhou    | 0.346 | 0.381 | 0.035       | 56.67             | −10.52            |
| Aba       | 0.352 | 0.604 | 0.251       | −7.28             | 26.14             |

Note: M-SE* and M-EE* indicate the average value of SE and EE from 2008 to 2018, respectively; Difference* indicates the absolute deviation between M-SE and M-EE of the city; SE growth rate and EE growth rate indicate the absolute growth rate of SE and EE from 2008 to 2018, respectively.
Conclusion and policy suggestion

The CCD model and the dynamic DM model were adopted to evaluate the coupling coordination degree between socio-economic (SE) and ecological environment (EE) of RBCs in Sichuan province. The evaluation results showed that the CCD of the nine RBCs in Sichuan province was not ideal, and there was a significant difference between SE and EE. It can be summarized in the following two aspects. On the one hand, seven cities were located to the level of primary coordination, tiny coordination, and mild dissonance, which accounts for 77.78%, and only two cities were located to the level of moderate coordination. In addition, there was a decline trend of the CCD in some years. On the other hand, the evaluation score of SE in eight cities was far behind that of EE in Sichuan province, which accounts for 88.89%, and there were six cities that showed significant difference between SE and EE.

It is found that the backward development of SE was the main obstacle to the uncoordinated development of RBCs. According to the above analysis of the SE and EE, this paper puts forward policy suggestions for urban and industrial transformation of RBCs in the following three aspects: (1) The government should increase the financial support and reduce tax for traditional transformation enterprises to improve competitiveness. For the high-tech industry and the green industry, higher financial support should be given to improve the proportion of the third industry, thereby realizing the improvement of the overall technology level and competitiveness of RBCs. (2) High-new technology should be paid more attention to improve the social production efficiency. Enterprises should actively introduce advanced technology to improve production efficiency, especially for traditional heavy industry, reducing carbon emissions, and environment pollution is a key task in the transformation process of RBCs. (3) The third is solving the problem of unemployment and labor loss caused by mine closure. The local government should increase the minimum wage of employees and increase social employment to stabilize social employment. Besides, increasing the subsidies for talent training and the cultivation of the natives in case of the excessive loss of labor also plays an important role in achieving sustainable development goals of RBCs.

In terms of different types of RBCs, resourced-growth cities and resource-depleted cities have great potential for resource exploitation, to avoid the transition to resource-depletion cities, and the adjustment of industrial structure should be strengthened to decrease the dependence on resource exploitation in the process of urban transformation. In addition, these cities should pay more attention to environmental protection and pollution control. For resource-depleted cities, the labor loss is the key problem to affect the comprehensive development of RBCs, and the government should take measures to increase employment rate, such as increasing the wages of employees and improving the welfare level of employees in local enterprises. For resource-regeneration cities, these cities should continue to improve the level of industrial upgrading in order to drive and radiate the transformation of surrounding cities.

Conflict or coordination? From what have been discussed above, it can be found that there are conflicts between socio-economic and ecological environment in the economically underdeveloped areas of China, and the socioeconomic development of resource-based cities in China’s economically underdeveloped areas is relatively backward. The transformation of resource-based cities should aim at win-win of economic growth and environmental protection; ignoring one of these aspects will hinder the sustainable development of RBCs. Therefore, to achieve the sustainable development goals of RBCs, it is necessary to coordinate the relationships among social security system, economic growth, environmental protection, and pollution control.

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Data availability The datasets used during the current study are available from the corresponding author on reasonable request.

Declarations

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