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Which Provincial Regions in China Should Give Priority to the Redevelopment of Abandoned Coal Mines? A Redevelopment Potential Evaluation Based Analysis

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Abstract: Abandoned mines have a double nature consisting of resources and assets, and their rational redevelopment is one of the most important practices of the recycling economy. To direct the layout of the regional abandoned mine redevelopment, this paper constructs a comprehensive assessment framework for abandoned mine redevelopment potential based on the driving force–state–response (DSR) model. It is quantitatively evaluated by three-dimensional cloud models, and the results are coupled using a four-quadrant approach. From the perspective of space control, this paper proposes classification principles of redevelopment potential and redevelopment sequence and summarizes the important policy implementations for each category. The paper studies the redevelopment potential of abandoned mines from the provincial perspective in 25 coal-producing provinces of China. The results indicate that not all areas with high resource potential are suitable for redevelopment. In the northern and western regions, the regional abandoned mines have high resource potential and strong redevelopment drivers. However, the spatial pattern of the suitability of the development conditions is not distributed in the same way as the resources. The distribution of the abandoned mine redevelopment potential reveals that the eastern and east-central regions should give priority to the construction of demonstration projects. Different driving force scenarios confirm that most provinces have no obvious driving factor preference, with a few exceptions. This evaluation model is established from a more comprehensive perspective and is a valuable aid for decision makers when arranging abandoned mine regeneration projects.

Keywords: abandoned coal mine; redevelopment potential; cloud model; DSR model; redevelopment sequence

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1. Introduction

An abandoned mine, also known as a mine closure or a closed mine, refers to the mine being closed permanently due to the depletion of its reserves or because of other premature closure reasons, such as the failure to meet safe mining conditions, community pressures, no standard regulations or policies, etc. [1] (Amirshenava and Osanloo, 2018). Along with the circular economy gaining popularity in China, people have paid more and more attention to the redevelopment of abandoned mines, not only because they contain a large number of reusable energy resources, such as residual coal and coal-bed methane, but also because they have abundant mine drainage, geothermal energy, underground space, tourism resources, etc. [2]. The inappropriate and irrational use of abandoned mines brought not only a huge waste of coal but also serious deterioration. Such severe influences on-site and off-site are outstandingly shown in the sharp economic recession, unemployment, ecological environment pollution, and so on [3–5]. Therefore, from the perspective of China's energy policy, environmental policy, and governance in general, the redevelopment of abandoned mines is imperative to mitigate the unintended consequences of the energy structure adjustment policies [6].

Abandoned mine redevelopment (AMR) refers to the reconfiguration of its functions by engineering, biological, and other measures to maximize the resource value. For example, the old underground tunnels can be reused as energy storage peaking power stations or heating centers [7], and the mining subsidence area can be reconstructed as a new energy base [8]. To improve the efficiency and quality of AMR and avoid the situation which is blossoming everywhere, it is urgent to make a quantitative assessment of the abandoned mine redevelopment potential (AMRP).

The AMRP means the potential ability that can be brought into play to promote the sustainable development of the AMR industry in competition with other regions under the comprehensive action of resource endowment, economic, social, and environmental demand, and social support capacity [9]. Consequently, as the basic work of AMR sequence planning, the assessment of AMRP has an important influence on maximizing the value of projects and reducing the investment risk [10].

As the world's largest producer and consumer of coal, China still maintains high-intensity coal mining. With the gradual implementation of the policy on reducing the coal capacity, the coal mines with poor reserves (reserves–production ratio of less than 5 years) or with backward productivity are being closed, which is leading to a drastic increase in the number of closed mines [11]. In 2016–2017 alone, the number of closed coal mines in China was about 3000. The number of coal mines in China began to decrease from more than 14,000 in the early stage of the 12th five-year plan to about 5800 by the end of 2018. Despite China having a relatively large number of abandoned mines, the resourceful reutilization effect of the abandoned mines is unsatisfactory. AMR is faced with many challenges. The most prominent manifestation is that the assessment system of the AMRP is not perfect and lacks the necessary data for supporting the layout of the redevelopment industry, which directly affects the redevelopment quality. The absence of a quantitative evaluation framework of the abandoned mines' values in China seriously hinders the redevelopment advancement.

According to the search conducted in Scopus, Google Scholar, and Crossref, there are few references for the assessment of AMRP. Currently, the scattered but valuable research is mainly concentrated on the aspects of value identification, management measures, and the development sequence of single resources such as mined land, industrial heritage, mining waste, and underground space. Bakhtavar et al. [12] studied the reuse of mined land and pointed out that the reuse model must be decided reasonably according to the effective evaluation of the economic factors and regional conditions. Sutherland [13] emphasized the industrial tourism value of abandoned mines and concluded that the development of industrial heritage should be combined with regional transformation to ensure the coordinated development of the economy and the environment. Lèbre et al. [14] revealed the recycling value of mining waste from three critical aspects: time, the extractive strategy, and the economic context. Kubit [15] comprehensively considered the influence of the regional economic development level, the labor force level, local employment, market demand, energy consumption, and the environmental conditions on the utilization of abandoned mining land after reclamation. Li et al. [16] proposed a driving force–state–response (DSR) model of abandoned coal mine industry square redevelopment, which integrates planning, land rehabilitation, and ecology, and analyzed the factors influencing the DSR framework. It can be seen that the current research is not comprehensive and in-depth with regard to the basic strategic issues, such as the study of regional abandoned mine redevelopment potential and redevelopment sequence. To our knowledge, no study has explored AMRP from the perspective of a provincial scale, and there is no quantitative assessment framework for AMRP, which presents an opportunity for the contributions of this paper.

Through analyzing the current research status and problems, this paper proposes a comprehensive indicator system for AMRP, including resource potential, driving force, and the suitability of development conditions based on the DSR mode. A complete index system is essential for assessing the comprehensive performance of AMRP. To reflect the contributions of the indicators, this paper calculates the indicators' weights by the improved analytic hierarchy process (IAHP) method to avoid the coincidence examination and the adjustment of the judgment matrix. Then, the cloud model is employed to calculate the potential level of the resource potential, the driving force, and the suitability of the development conditions to take into account, respectively, the randomness and fuzziness of the indicators. The level of AMRP is determined by these three dimensions, and this paper therefore uses the four-quadrant method with a bubbles map to couple the results of the driving force (D), the resource potential (state), and the suitability of the development conditions (response) and, finally, to comprehensively classify the redevelopment potential and redevelopment sequence of regional abandoned mine development. Then, ArcGIS is used to discuss the spatial patterns of the three dimensions and to analyze the regional differences, respectively.

2. Components of Abandoned Mine Redevelopment Potential

Based on the PSR model developed by the United Nations Commission on Sustainable Development (UNCSD), the driving force–state–response (DSR) model was constructed for sustainable assessment [17]. According to the DSR framework, this paper proposed the assessment system of the AMRP from three dimensions. The interactions of the dimensions are demonstrated in Figure 1, where "driving force" is the fundamental factor that causes the changes of the "state", "State" is the constraint condition for the realization of "Driving force" and the basic basis for the formulation of "Response", and the "Response" is an important way to promote the change of the "State".

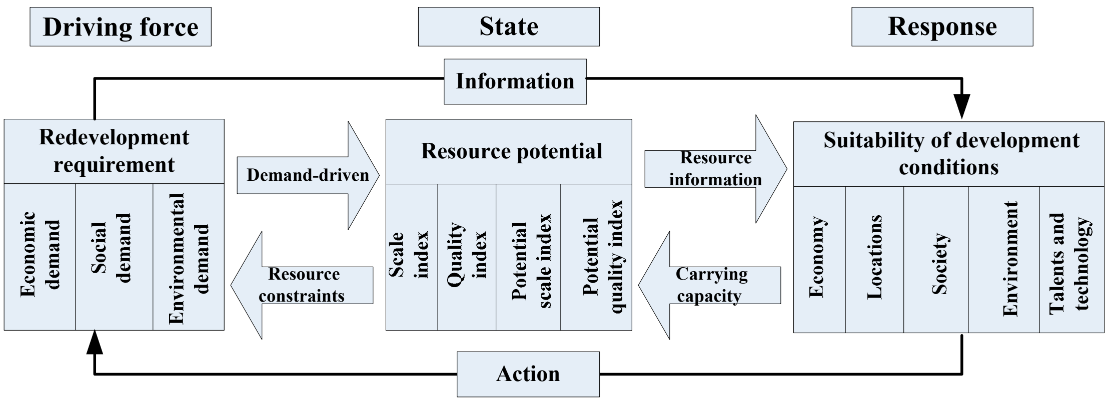

Figure 1. DSR model of abandoned mine redevelopment potential.

2.1. Driving Force

As AMR can contribute to the region socially, economically, and ecologically, the driving force is oriented to the performance of AMR [18]. Due to the performance being difficult to express quantitatively, this paper adopts the requirements of the regional sustainable development of mining and society to reflect the driving force indirectly. The more in demand it is in the region, the better the benefit and the stronger the driving force. According to the triple bottom line principle of sustainability, the demands of AMR are mainly identified from the economic, social, and environmental aspects [19,20]. The economic demand indicators are selected from the impacts of mine closure on the regional economy and financial revenue. Due to the absence of added value data on the coal mining industry, this paper replaces this indicator with mining investment. The social demand indicators stem from two aspects: the influences of mine closure on society and the resource constraints of social development. The environmental demand indicators come from the environmental carrying capacity. As the emissions data of wastes in the provincial area are unavailable, this paper uses the "Per unit GDP energy consumption" to indirectly reflect the environmental pollution. All the detailed indicators of driving force are listed in Table 1.

Table 1. Summary of driving force indicators.

Principle	Criteria	Indicators	Measure	Reference
Driving force	Economic demand	Share of mining investment D_1 (‰)	Investment of mining/Total investment	Cui et al. [21]; Cao [22]
		Share of resource tax D_2 (%)	Resources tax/Tax revenue	Batterham [23]; Groth and Schou, [24]
	Social demand	Share of the average wage of mining staff D_3	The wage of mining employees/Average annualwage	Unger et al. [25]; Nehring and Cheng [26]
		Share of mining staff D_4 (‰)	Mining employees/Total employees	Amirshenava and Osanloo, [1]; Laurence [19]
		Population density D_5 (people/km^2)	Total population/Total area	Wang et al. [27]; Volk et al. [28]
		Urbanization rate D_6 (%)	Urban population/Total population	Ruan et al. [29]; Zhang et al. [30]
	Environmental demand	Per unit GDP energy consumption D_7 (tons/CNY 10,000)	Unit GDP energy consumption	Gorman and Dzombak [3]; Mishra et al. [31]
		Vegetation coverage D_8 (%)	Coverage space of green areas/Total area	Laurence [19]; Amirshenava and Osanloo [20]

2.2. State

The "State" refers to the basic conditions of the abandoned mines, which reflects the resource potential available for redevelopment. Due to a large number of abandoned mines, various types of residual resources, and the shortage of value classification standards for the various resources, it is difficult to recognize the value of the abandoned mine and evaluate the resource potential of the regional abandoned mines. Therefore, from the perspective of data availability and quantitative analysis, this paper adopts the scale index and quality index to measure the resource ontology characteristics of the abandoned mines [32]. The scaled index refers to the number of abandoned mines in a region, and a large number of abandoned mines is certain to bring out industry-scale effects [33]. The quality index is explained as the average capacity of the regional closed mines. The fact is that most of the small-scale mines operated using poor mining technology, which resulted in serious damage to the underground space. Moreover, the incomplete mine information causes the low redevelopment value of these mines. Therefore, the larger the capacity, the easier the abandoned mines will be to redevelop. The quantity and quality of the "potential resources" of the abandoned mines are the important basic foundation for future redevelopment. These indicators are the final determinants of whether the regional abandoned mines have the development possibility in the future. To facilitate quantitative analysis, the number of existing mines and the average capacity of these mines are adopted to reflect the value characteristics of the potential resources. The indicators of resource potential are presented in Table 2.

Table 2. Summary of resource potential indicators.

Principle	Criteria	Indicators	Measure	Reference
Resource potential	Resources status index	Scale index R_1 (a)	Number of closed mines	Chang et al. [34]; Caulk et al. [35]
		Quality index R_2 (Mt/a)	The average capacity of closed mines	Bakhtavar et al. [12]; Naidu et al. [36]
	Potential resources index	Potential scale index R_3 (a)	Number of existing mines	Mishra et al. [26]; Zhang et al. [37]
		Potential quality index R_4 (Mt/a)	The average capacity of existing mines	Nehring and Cheng [26]; Wang et al. [38]

2.3. Response

The evaluation of AMRP cannot exist away from the regional conditions [25]. The "response" mainly considers the support degree of the local development conditions in the economy, infrastructure, technology, governmental ability, and so on. This paper uses the suitability of development conditions to reflect the response of a region. It should be pointed out that the locational conditions directly affect the redevelopment potential [39]. If the locational conditions are extremely good, the mail addressed to the area will get sent elsewhere. The better the support, the stronger the support degree became. Based on the works of the literature reviews, this paper classified the suitability of the external conditions into economy, locational conditions, talent science and technology, environmental support, and social support. The indicators of the response are shown in Table 3.

Table 3. Summary of the suitability of redevelopment condition indicators.

Principle	Criteria	Indicators	Measure	Reference
Suitability	Economic support	GDP S_1 (CNY 100 million)	–	Unger et al. [25]; Bangian et al. [40]
		Disposable income S_2 (per capita)	–	Gorman and Dzombak [3]; Bangian et al. [40]
	Locational conditions	Road area ratio S_3 (%)	Road area/Total area	Kubit [15]; Cui et al. [21]
		Degree of openness S_4 (%)	Foreign investment/GDP	Song et al. [41]; Lee and Chou [42]
		Share of tertiary industry S_5 (%)	The GDP of tertiary industry/GDP	Chang et al. [34]; Zhu et al. [43]
	Talents and technology	Research investment level S_6 (%)	The funds of R&D/GDP	Song et al. [41]; Miremadi et al. [44]
		Share of talents S_7 (people)	University and College student enrollmentper 100,000 persons	Wang et al. [27]; Zhou et al. [45]
	Environmental support	Industrial pollution control investment level S_8 (‰)	Investment in industrial pollution control/GDP	Cui et al. [21]; Chang et al. [34]
		Share of environmental protection charge S_9 (%)	Environmental protection charge/Financial expenditure	Naidu et al. [36]; Bangian et al. [40]
	Social support	Social security and employment S_{10} (%)	Social security and employment expenditure/Financial expenditure	Chang et al. [34]; Knierzinger and Sopelle [46]
		Expenditure for S. E. C. H S_{11} (%)	Science–education–culture–health expenditure/Financial expenditure	Cui et al. [21]; Wang et al. [47];
		Share infrastructure investment S_{12} (%)	Investment in electricity, gas, water, traffic, transport, storage, post/Fixed assets	Wang et al. [27]; Zhang et al. [30]

3. Methodologies

3.1. Cloud Model for Abandoned Mine Redevelopment Potential

3.1.1. The Basic Theory of the Cloud Model

The evaluation of potential is a multi-dimensional decision-making process, and the evaluation method should take into account the randomness and fuzziness of uncertain concepts to obtain more scientific results. The cloud model is a powerful tool to realize the transformation between the quantitative concepts and the qualitative data by cloud generators. The forward cloud generator is used to convert the cloud model to the specific value. The algorithm is described in Table A1. The one-dimensional normal cloud, constructed based on the normal distribution and Gaussian membership function, is a very important cloud model with general applicability. It has been widely applied in environmental assessment [48], risk assessment [49], artificial intelligence [50], and so on. The normal cloud model discards the traditional membership function but uses three numerical features, namely expected (*Ex*), entropy (*En*), and super entropy (*He*), to describe the fuzziness and randomness of the indicators. The description of each parameter and the calculation formulas are shown in Table 4 by referring to [21]. To illustrate the cloud model more clearly, we present a cloud figure corresponding to the cloud parameters (0.5, 0.1, 0.02). It can be seen in Figure 2 that the expectation value is 0.5 with a variation range (0.2–0.8) based on the "3En criterion". The span of the cloud image reflects the fuzziness, and the cloud image thickness interprets the randomness of the concept.

Table 4. Descriptions of parameters.

Parameters	Original Descriptions	Algorithm of Cloud Parameter
Ex	The best sample point of concept quantization	$Ex_{ij} = \left(x_{ij}{}^{\min} + x_{ij}{}^{\max}\right)/2$
En	Fuzzy degree of a qualitative concept	$En_{ij} = \left(x_{ij}{}^{\max} - x_{ij}{}^{\min}\right)/2.355$
He	Uncertain degree of entropy	Determined by testing results

Note: the $x_{ij}{}^{\min}$ and $x_{ij}{}^{\max}$ represent the minimum and maximum values of one indicator with a bilateral constraint.

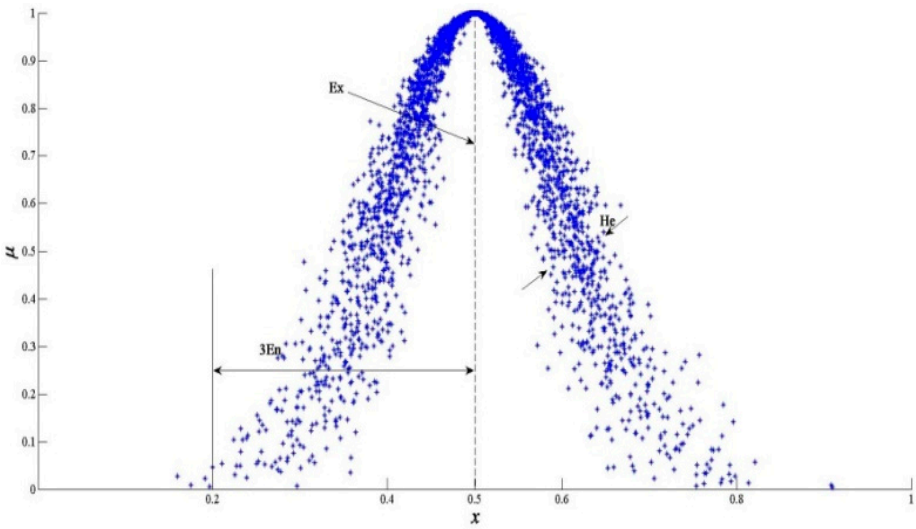

Figure 2. Normal cloud model corresponding to an indicator.

3.1.2. Evaluation Process for AMRP Based on Cloud Model

The assessment processes by the normal cloud method are shown as follows:

Step 1: Set the indicator sets, weight sets, and estimation sets

Based on the multidimensional decision theory, the paper proposed three indicator sets, $U_1 = \{D_1, D_2, \ldots, D_8\}$, $U_2 = \{R_1, R_2, R_3, R_4\}$, and $U_3 = \{S_1, S_2, \ldots, S_{12}\}$, where the elements of these sets are derived from the driving force, the resource potential, and suitability of the development condition, respectively. Accordingly, there are three weight sets $W_1 = \{WD_1, WD_2, \ldots, WD_8\}$, $W_2 = \{WR_1, WR_2, WR_3, WR_4\}$, and $W_3 = \{WS_1, WS_2, \ldots, WS_{12}\}$ to respond to the three indicator sets. The estimation set can be described as $V = \{V_1, V_2, \ldots, V_5\}$ = {Lower, Lower, Moderate, High, Higher}, where the number 5 represents 5 assessment grades.

Step 2: Grade the cloud model

The indicators' intervals are first determined by the mean variance classification method. Then, the cloud parameters of all the indicators can be calculated by the computation formula given in Table 4. The cloud parameters of the indicators used in this paper are shown in Table A2.

Step 3: Obtain the certainty degrees of the indicators

Inputting the collected basic data of the 24 indicators into the forward cloud generator and calculating the average membership value by repeating 100 times, we can obtain the subordinate degrees of the evaluated indicators that belong to different grades. The three membership matrixes U_i (i = 1, 2, 3) are obtained by Equation (1):

$$U_i = \begin{vmatrix} \mu_{11} & \cdots & \mu_{15} \\ \vdots & & \vdots \\ \mu_{n1} & \cdots & \mu_{n5} \end{vmatrix} \quad (1)$$

where n refers to the indicator number of each dimension, and 5 represents the assessment grades.

Step 4: Determine the level of the three dimensions

Combining the weight matrices W_i (i = 1, 2, 3) calculated in Section 3.2, the grade memberships of the different dimensions are acquired by Equation (2):

$$R = W \times U \quad (2)$$

where $R = (r_1, r_2, \cdots, r_5)$, and r_j indicates the degree of membership that belongs to C_j (j = 1, 2, 3, 4, 5). The unfitness of the maximum membership principle could be overcome by the feature value of grades (FVG) for the results quantification, and the calculation formula is given in Equation (3). The final assessment results are demonstrated in Table A3.

$$R = \sum_{k=1}^{5} kR_k / \sum_{k=1}^{5} R_k \quad (3)$$

3.2. Indicators Weights by Improved AHP

The analytic hierarchy process (AHP) is the most common method for determining the weight [51]. However, with the relatively complex indicator system of AMRP (three dimensions with 24 indexes), there are some problems in the AHP. The major problem in the practical application is how to examine and correct the consistency of the judgment matrix, which greatly limits its application. For the sake of the efficient determination of the indicators' weights, this paper adopts the scale-extending method to improve the traditional AHP (IAHP). The construction processes of the judgment matrix by the IAHP are as follows. Firstly, all the criteria layer indicators are to be ranked according to the order of their importance. The importance value as judged by the individual expert's opinion is referred to the nine-point scale proposed by Saaty (see Table A4). The obtained importance sequence of the indicators is set as $x_1 > x_2 > x_3 > \cdots > x_n$. Then, the judgment matrix R which has a satisfactory consistency is shown in Equation (4). The indicators' weights can be calculated by Equation (5).

When the criteria layer indicators' weights are determined, we can determine the index layer indicators' weights by the same algorithm. The global weights of all the indicators are calculated by multiplying the criteria layer indicators' weights by the corresponding index layer indicators' weights. The improved AHP method avoids the coincidence examination and the adjustment of the judgment matrix, which simplifies the calculation and defines the weighing more scientifically and more properly.

$$R = \begin{vmatrix} 1 & t_1 & t_1t_2 & t_1t_2t_3 & \cdots & t_1t_2\cdots t_{n-1} \\ 1/t_1 & 1 & t_2 & t_2t_3 & \cdots & t_2t_3\cdots t_{n-1} \\ 1/t_1t_2 & 1/t_2 & 1 & t_3 & \cdots & t_3t_4\cdots t_{n-1} \\ 1/t_1t_2t_3 & 1/t_2t_3 & 1/t_3 & 1 & \cdots & t_4t_5\cdots t_{n-1} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 1/t_1t_2\cdots t_{n-2} & 1/t_2t_3\cdots t_{n-2} & 1/t_3t_4\cdots t_{n-2} & 1/t_4t_5\cdots t_{n-2} & \cdots & t_{n-1} \\ 1/t_1t_2\cdots t_{n-1} & 1/t_2t_3\cdots t_{n-1} & 1/t_3t_4\cdots t_{n-1} & 1/t_4t_5\cdots t_{n-1} & \cdots & 1 \end{vmatrix} \quad (4)$$

$$w_i = \sqrt[n]{\prod_{j=1}^{n} r_{ij}} / \sum_{i=1}^{n} \sqrt[n]{\prod_{j=1}^{n} r_{ij}} \tag{5}$$

where w_i is the weight value of the i-th indicator given by an individual expert; r_{ij} is the value of the preference of the i-th compared to the j-th element.

Due to the weights being determined by a group of experts, the experts' preferences expressed by the IAHP judgment matrix in group decision making should be effectively integrated. The most common way is to fuse all the experts' judgment matrices into one judgment matrix by the weighted geometric average (WGA) method [51]. The judgment matrix elements are calculated according to Equation (6):

$$a_{ij} = (a_{ij}, 1)^{2_1} \times (a_{ij}, 2)^{2_2} \cdots (a_{ij}, m)^{2_k} \tag{6}$$

In Equation (6), k represents the number of experts, (a_{ij}, k) is the matrix element of the k-th expert, and λ_k indicates the weight of each expert. As the weight of the experts is difficult to determine, this article assumes that the importance of each expert is of equal weight; so, Equation (6) can be simplified as Equation (7). The final weights results are listed in Table 5.

$$a_{ij} = \sqrt[k]{(a_{ij}, 1) \times (a_{ij}, 2) \cdots (a_{ij}, m)} \tag{7}$$

Table 5. Weights of indexes for AMRP.

Indicator	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	R_1
Weight	0.2952	0.1148	0.0495	0.0627	0.1221	0.0957	0.0962	0.1638	0.1190
Indicator	R_2	R_3	R_4	S_1	S_2	S_3	S_4	S_5	S_6
Weight	0.2210	0.2904	0.3696	0.2665	0.1435	0.1696	0.1120	0.0384	0.0434
Indicator	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}			
Weight	0.0266	0.0512	0.0288	0.0156	0.0156	0.0228			

Note: D, R, and S correspond to 3 criteria in Tables 1–3, and each criterion has its representative indexes. For example, D_1, D_2; R_1, R_2.

4. Results and Discussion

4.1. Spatial Patterns of AMRP

Because a coal mine that has been closed for many years is hard to reuse (except for the land and part of the facilities), this paper mainly focuses on the mine's closed redevelopment since the implementation of the coal capacity cut policy in 2016. Based on the basic data collected in Tables 1–3 in 2017, this article adopts the normal cloud model to assess the grades of abandoned mine resource potential, the driving force, and the development condition suitability, respectively. The feature value of the grade results is shown in Table 6. The potential evaluation results of the three dimensions are divided into 5 grades by the Jenks method in ArcGIS 10.2, and the grade distribution diagrams are obtained through the technology of spatial visualization. As can be seen in Figure 3a–c, the darker the color, the higher the grade. To support the demonstration and analysis of the results, this paper also presents a spatial distribution diagram that reflects the information on the total coal consumption, the economic aggregate, and the basic reserves of coal in 2017 in Figure 3d. Furthermore, the per capita water resources and the number of mines and the coal production capacity by region in China are given in Figure 3e,f, respectively, to compare the evaluation results.

Table 6. The results of FVG by cloud model-based assessment approach.

Provinces	FVG_D	FVG_R	FVG_S
BJ	2.2847	2.9734	3.2224
HE	2.6134	2.4853	2.6675
SN	3.2856	4.2241	2.4914
IM	4.1816	3.8994	2.1749
LN	2.8181	2.7182	2.9173
JL	2.1992	1.5017	1.7978
HL	3.1129	2.5864	1.7260
JS	2.6535	2.8650	4.0202
AH	2.3694	3.3482	2.5481
FU	1.6831	1.2059	3.1962
JX	1.5874	1.9861	2.0699
SD	2.7071	2.8110	3.7028
HA	2.3323	2.4206	2.8950
HB	1.8728	1.4041	2.8215
HN	1.7588	2.4293	2.6578
GX	1.4890	1.6063	1.7661
CQ	2.1834	1.4982	2.4834
SC	1.9476	2.4475	2.4940
GZ	2.5363	2.5652	1.4699
YN	1.8492	1.4198	1.5801
SX	2.9681	3.4581	2.1046
GS	2.6743	2.0523	1.7637
QH	3.4969	1.2526	1.6723
NX	3.8297	3.2973	2.3382
XJ	4.0099	2.9757	1.5724

Note: Table A5 lists the 25 provincial administrative units used for this study, with their abbreviations. FVG_D, FVG_R, and FVG_S are the feature values of the grades of the driving force, resource potential, and the suitability of development conditions, respectively.

The driving force score is shown in Figure 3a; the provinces with a high driving force ($FVG_D \geq 2.96$) are Inner Mongolia, Xinjiang, Ningxia, Shanxi, and Shaanxi, which belong to the northwest region. Combined with Figure 3d, it can be seen that the richer the province in terms of natural resources, the stronger its driving force ranking. However, these provinces' economies rely heavily on coal production. Such a phenomenon is outstandingly shown in three aspects: the high proportion of the added value of the coal industry, the huge coal consumption, and the high proportion of mining workers. With the changing international environment and market environment, the traditional industrial strategy of resource exploitation and simple economic structure would suffer more. As can be seen in Figure 3e, the distribution of water resource reserves is the reverse of that of the coal resources. As the carriers of ecological benefits, the water resources have been seriously damaged by the processes of coal exploitation. If the water resources are not effectively protected in the process of mine closure, the pollution and destruction will be further aggravated. With the continuous implementation of the policy of cutting the coal capacity, the development of these provinces with severe overcapacity will face more sustainable development problems, which could lead to a strong endogenous impetus for abandoned mine redevelopment [6]. The driving force of the southern provinces is relatively weak. The reason can be explained by two factors: the relatively optimized industrial structure and the low dependence on resource exploitation [43]. It should be noted that the driving force of some of the eastern provinces which have satisfactory economic situation, such as Shandong, Jiangsu, and Hebei, is stronger than that of the southern provinces, which may be caused by overpopulation density, lack of water resources, and strong resource constraints [52].

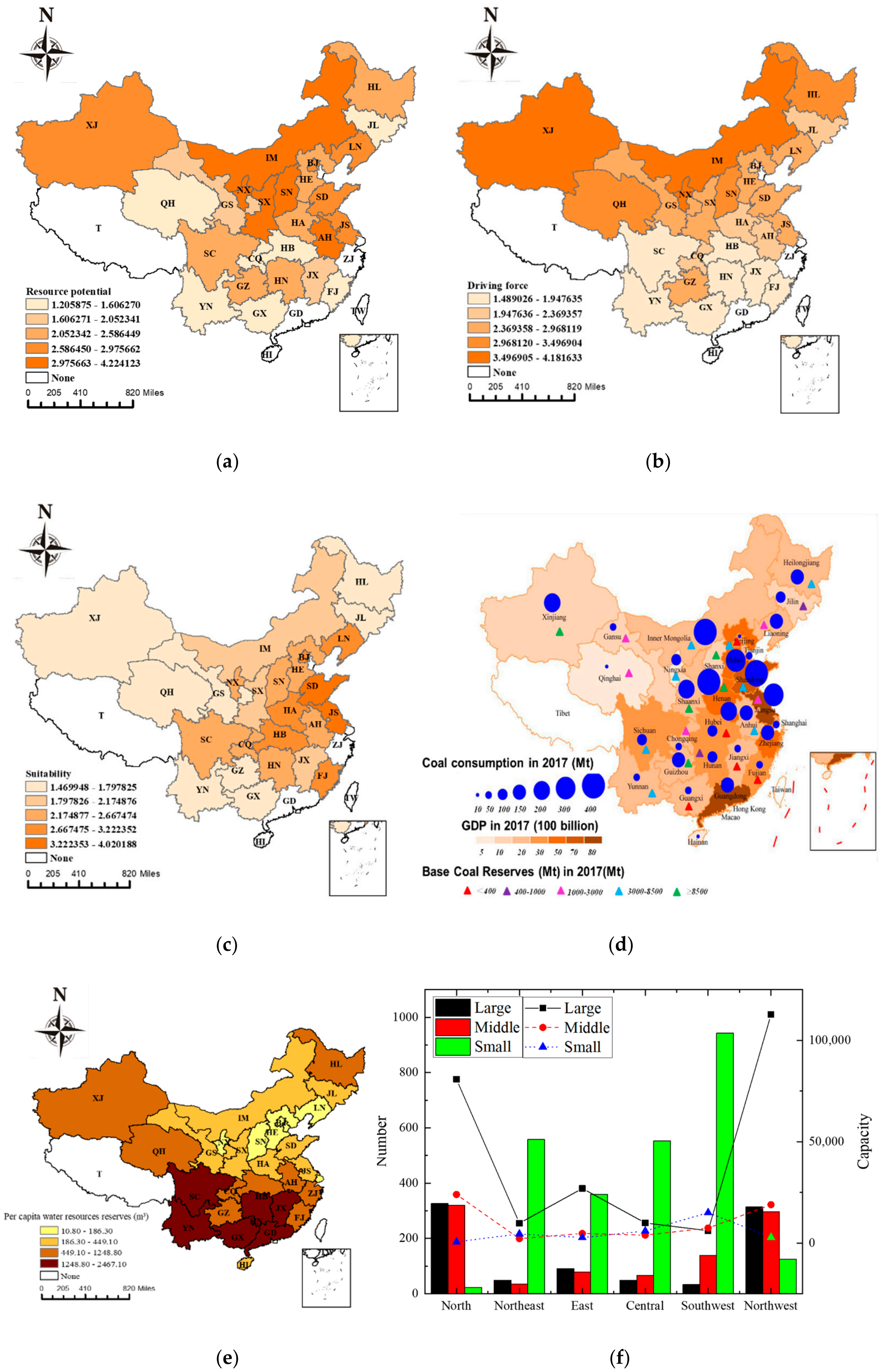

Figure 3. Spatial distribution in three dimensions of AMRP.

In terms of the resource potential demonstrated in Figure 3b, the areas with high resource potential ($FVG_R \geq 2.97$) include Shanxi, Inner Mongolia, Shaanxi, Ningxia, Xinjiang, Anhui, and Beijing. On the whole, the distribution of the abandoned mines' resource potential corresponds to the reserve distribution of the coal resources, as shown in Figure 3d. It can be seen in Figure 3f that in north and northwest areas, the medium and large mines occupy the dominant position, while in the southwest, central, and northeast regions, the coal mines are driven mainly by small-scale operations. According to the 13th five-year plan of the coal industry [53], the central and eastern provinces such as Beijing and Anhui should compress the scale of coal production, and the northern and western provinces need to harmonize the environmental protection and coal mining due to the fragile ecological environment. Therefore, with the background that the country is devoted to reducing excess coal capacity and strengthening ecological protection, the resource potential of these provinces, which have a long history of coal mining and many backward mines, is high. As for the southern provinces, such as Fujian, Jiangxi, Guangxi, Sichuan, and Yunnan (southwest in Figure 3f), it is necessary to speed up the closure of coal mines because of the sporadic distribution of resources and backward production capacity. However, even though the numbers of abandoned mines look great, the vast majority of them belong to small mines. That is why the southern provinces have a low resource potential.

The suitability of the development conditions in China has greater diversity among various regions, as shown in Figure 3c. The reasons could be described by the fact that the differences in regional economic development, geographical location, and traffic conditions directly affect the level of suitability. The distribution pattern of this indicator can be described as follows: the east region is the best, followed by the middle, and the west and southwest are the weakest [21]. As can be seen in Figure 3d, relative to the western regions, the middle and east regions, including Beijing, Shandong, Jiangsu, Fujian, and Liaoning, have a good economic development basis and regional advantage. Therefore, according to the theory of the grades development, the abandoned mine redevelopment industry should give priority to the mining areas of the eastern and central regions because these are the regions with high resource potential and strong driving forces.

4.2. Category Classification of Redevelopment Potential and Redevelopment Sequence

Considering that the AMRP is influenced by three dimensions, this paper adopted the four-quadrant method combined with a bubbles map (Figure 4) to comprehensively position the AMRP level into specific categories, and finally, it sorted the four quadrants according to different goal orientations. Based on the comprehensive consideration of the basic conditions of the abandoned mines and the suitability of the development conditions, this article proposed the classification principles of "resource advance and coordinate development" and divided the AMRP into five classes: higher, high, moderate, low, and lower. Figure 5 is the scatter diagram with the values of the three dimensions of the 25 provinces. It is divided into four quadrants according to the feature value of the grade medians of the driving force and the suitability of the development conditions. The resource potential is displayed as a bubble map, with the various colors representing different grades of resource potential, where the colored bubbles indicate that the resource potential feature value of the grades is above the median, while the black bubbles represent the values below the median. In Figure 5, the first quadrant represents "High Driving Force-High Suitability (HDFHS)", and the colored bubbles in this quadrant denote the higher redevelopment potential areas. The second quadrant is expressed as "Low Driving Force-High Suitability (LDFHS)", and the colored bubbles in this quadrant indicate the high redevelopment potential areas, while the black bubbles are the low potential areas. The third quadrant signifies "Low Driving Force-Low Suitability ((LDFLS)", and the black bubbles in this quadrant indicate the lower redevelopment potential areas. The fourth quadrant is depicted as "High Driving Force-Low Suitability (HDFLS)", and the colored bubbles in this quadrant indicate the high redevelopment potential areas, while the black bubbles are the low potential areas. According to the planning principles of "progressive order, progressive development, long-term planning, and timely development", the redevelopment sequence is classified into four broad categories: "Urgent action, Recent planning, Medium-term planning, and Long-term planning". The "Recent planning" and "Medium-term planning" phases are further divided into three stages, respectively, according to the combined relationship between the three dimensions. The specific grades of redevelopment potential, redevelopment sequence, and the combination relationship between the conditions are shown in Table 7. According to the different redevelopment stages, the action and emphasis of policy implementation for each redevelopment stage are put forward, respectively.

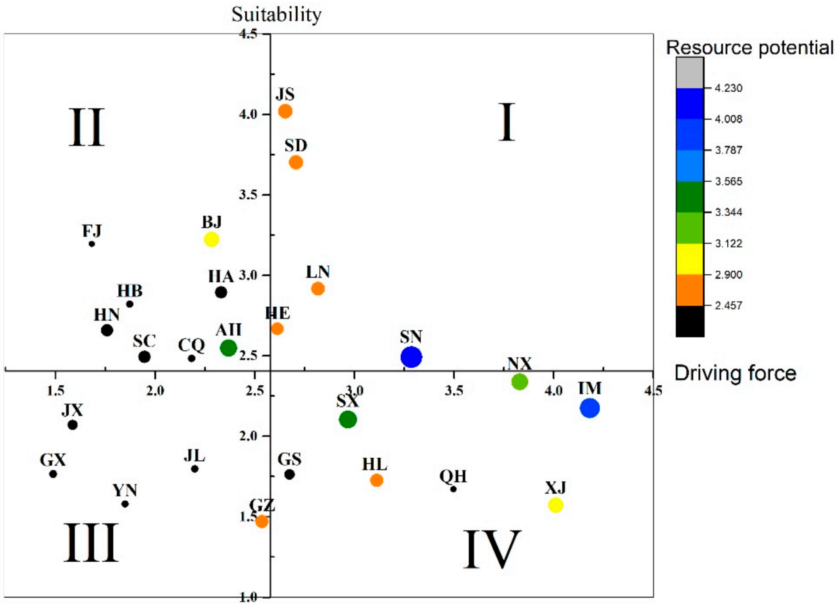

Figure 4. Scatter plot of the resource potential, driving force, and development conditions suitability.

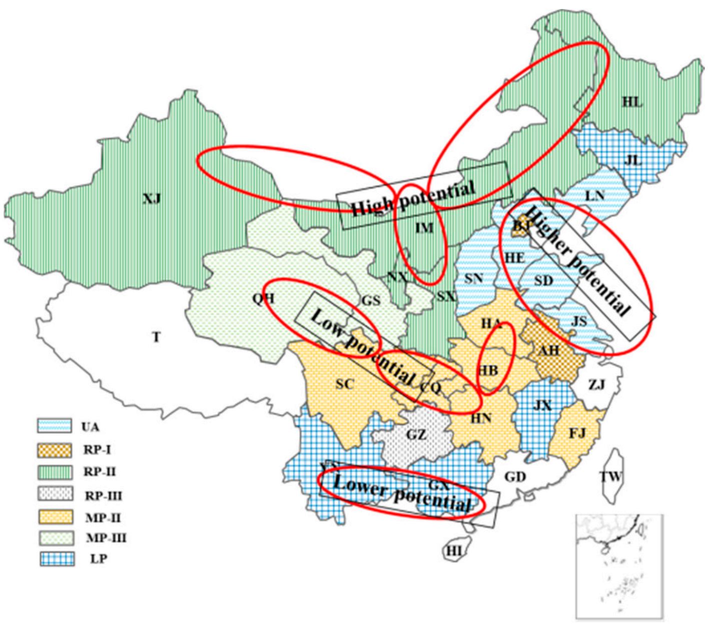

Figure 5. Province classification of redevelopment potential and redevelopment sequence.

Table 7. Ranking of abandoned mine redevelopment potential and redevelopment sequence planning.

Conditions			Redevelopment Potential	Redevelopment Sequence	Action and Emphasis
D	S	R			
•	•	•	Higher potential	Urgent action (UA)	➢ Compile urgent strategic planning ➢ Correct improper development ➢ Set standards and policies
○	•	•		Recent planning-I (RP-I)	➢ Detailed development plan ➢ Expand tactics and market benefit ➢ Major project investment argument
•	•	○	High potential	Recent planning-II (RP-II)	➢ Detailed development plan ➢ Necessary project implementation guarantee ➢ Extraterritorial capital and technical cooperation
○	•	○	Moderate	Recent planning-III (RP-III)	➢ Resource protection and enhancement measures ➢ Cost-effectiveness argument ➢ Major project implementation argument ➢ Necessary project implementation guarantee
•	○	•	Low potential	Medium-term planning-I (MP-I)	➢ Re-identify the resource potential ➢ Extraterritorial deployment of capital technology
○	○	•	Lower potential	Medium-term planning-II (MP-II)	➢ Re-identify the resource potential ➢ Expand tactics and market benefit ➢ Extraterritorial deployment of capital technology
•	○	○		Medium-term planning-III (MP-III)	➢ Re-identify the resource potential ➢ Major project implementation argument ➢ Extraterritorial capital and technical cooperation
○	○	○		Long-term planning (LP)	without considering

Note: D = driving force, S = resource potential, R = suitability of development conditions. The black dot • indicates that the value is equal to or greater than the median, and a white dot ○ indicates that the value is less than the median.

Following the combination of Figure 5 and Table 7, the spatial pattern of the redevelopment potential and the redevelopment sequence of China's provinces are shown in Figure 6. It can be observed that Jiangsu, Shandong, Liaoning, Hebei, Shanxi, Anhui, and Beijing are "higher potential" provinces. Among these provinces, the first five provinces with the higher resource potential, driving force, and suitability of development conditions values are suggested to be the first abandoned mine redevelopment project demonstration zones. Beijing and Anhui are at the "Recent planning-I (RP-I)" stage. Shaanxi, Ningxia, Inner Mongolia, Heilongjiang, and Xinjiang are regarded as the "Recent planning-I (RP-II)" stage. The regions with better performance in only one dimension, such as Guizhou, Fujian, Hubei, Hunan, Sichuan, Chongqing, Henan, Gansu, Qinghai, etc., can be evaluated as "potential development zones" for the abandoned mine resources redevelopment. Yunnan, Jiangxi, Guangxi, and Jilin performed the worst in all three dimensions; therefore, the abandoned mines in these areas were suggested only for ecological rehabilitation but not redevelopment.

4.3. Key Indicators for AMRP

Owing to the various types of abandoned mines, China's AMRP level varies according to the region, with differences in the regional advantage and the basis of the regional economy. The radar chart method was adopted to reflect the indicators' difference of objects (Figure 6) in order to reveal the key indicators restricting the AMRP.

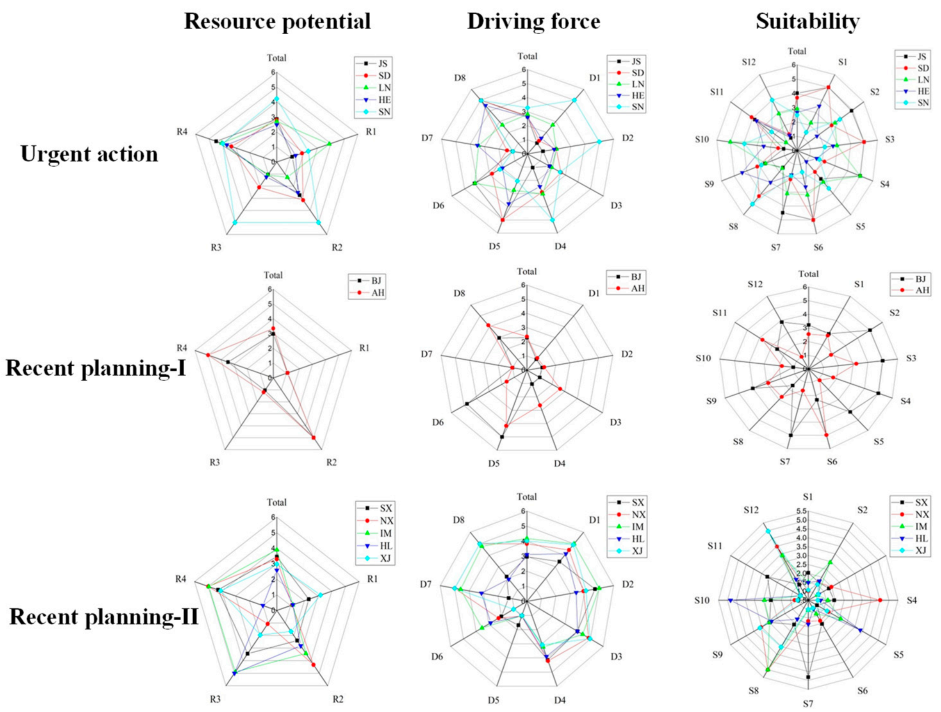

Figure 6. Inter-domain comparison in the same redevelopment stage.

For the provinces in the "Urgent action" phase, although the three dimensions performed relatively better than in the other areas, they still need to improve the relatively weak indicators to enhance the redevelopment potential. Take Shanxi as an example; as the key coal producer in China, Shanxi has lots of abandoned mines with large sizes; so, the resource potential grade is high. Many typical phenomena of a resource-based economy, such as the simplification of a leading industry, unreasonable economic structure, and high dependence on resources, lead to the strong driving force in Shanxi. However, the suitability of the development conditions is lower than that of Jiangsu and Shandong, which is prominently manifested in the economic scale (S_1), the traffic conditions (S_3), the opening level (S_4), the intensity of the input into science and technology (S_6), and the investment in environmental protection (S_9). Therefore, Shanxi should continue to strengthen investment in infrastructure construction, science and technology, and environmental protection and should actively introduce foreign capital to enhance the suitability of the external conditions [22].

For the provinces in the "Recent planning-I" phase, Anhui's resource potential is higher than that of Beijing, but its development conditions are far behind those of Beijing. It should be pointed out that Beijing's investment intensity in scientific research (S_6), industrial pollution control (S_8), and science, education, culture, and health (S_{11}) is insufficient. As for the driving force, due to the high population density (D_5) and strong environmental and resource constraints (D_6 and D_8), Beijing urgently needs to develop mined land and underground space to release more urban development space, while Anhui's driving force mainly comes from the social and environmental impact caused by mine closure (D_3 and D_4).

For the provinces in the "Recent planning-II" phase, although the resource potential and driving force of these areas are strong, the suitability of the development conditions limits their redevelopment. It can be seen that the driving forces of Xinjiang and Inner Mongolia are significantly higher than those of Shaanxi, Ningxia, and Heilongjiang, but the resource potential of Xinjiang and Heilongjiang is not as good as that of Inner Mongolia. As for the indicators of the suitability for development conditions, except for the proportion of infrastructure investment, Xinjiang is at a disadvantage in terms of the economy, location, talent science and technology, social security, and other indicators. Ningxia has the best performance in capital opening and industrial pollution investment, while the other indicators need to be improved. However, driven by the development policy in western China, the infrastructure and economic scale of the western region will be greatly improved, and the suitability of the development conditions will change qualitatively [53].

4.4. Different Driving Force Scenarios

It can be seen in Table 4 that the weights of economic demand account for 41% of the total driving force weights, while the weights of social demand and environmental demand account for 33% and 26%, respectively. Therefore, under the distribution of the existing weights, the redevelopment priority is given to meeting economic demand. This scenario was regarded as the economic priority scenario. However, different provinces may have various redevelopment preferences. Therefore, this article gives two other driving force scenarios to illustrate the performances of all the provinces under different demand priorities. The first one is the social priority scenario, which was devoted to increasing re-employment, reducing the impact on miners' lives, and solving the resource constraints of sustainable development. In this scenario, the weights for social demand were set as 0.5, while the weights of economic demand and environmental demand were 0.25, respectively. The results in this scenario are shown in Figure 7. The second scenario is the environmental priority scenario, which emphasizes environmental protection and energy savings. In this scenario, the weight of environmental demand was set as 0.5, while the weights of economic demand and social demand were 0.25, respectively. The results are presented in Figure 8.

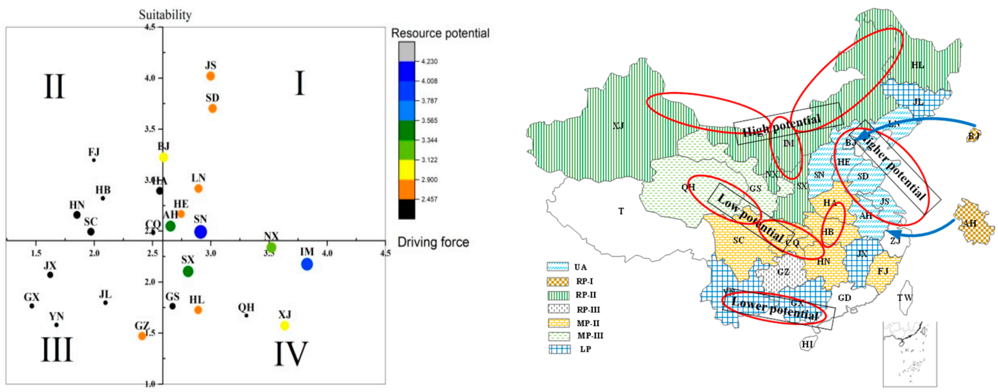

Figure 7. Results under social priority scenario.

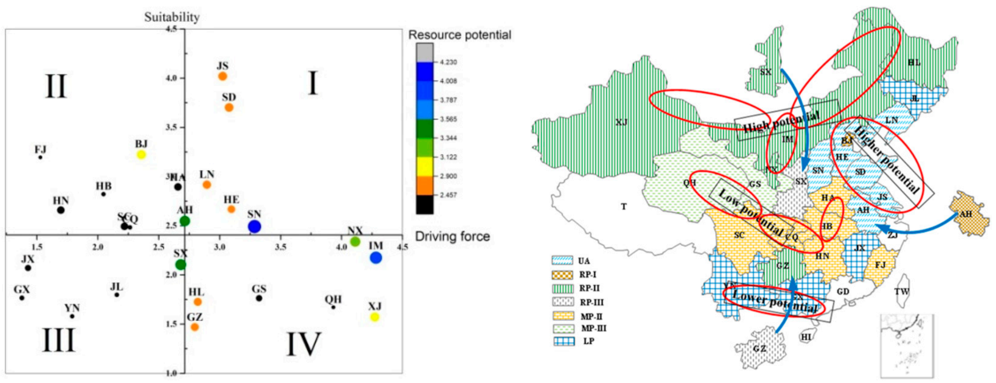

Figure 8. Results under environmental priority scenario.

By comparing with the results of the economic priority scenario, it can be found that, although the indicators values were changed under different scenarios, the redevelopment potential and redevelopment sequence classification of most provinces remain unchanged, which proves that most provinces have no obvious preference for the benefits of abandoned mine redevelopment. However, under the social priority scenario (Figure 7), the redevelopment sequence of Beijing and Anhui moved from "Recent planning-I" up to "Urgency action", which indicates that the redevelopment of abandoned mines in these two provinces should pay more attention to the social requirements compared to the economic needs. This conclusion has been verified in Section 4.3; that is, Anhui province should mainly address the problem of unemployment, while Beijing should focus on solving the resource and environmental constraints faced by urban development. In the environmental priority scenario, the redevelopment sequence of Anhui, Guizhou, and Shaanxi is changed (in Figure 8). Specifically, the redevelopment sequence of Anhui was changed from "Recent planning-I" up to "Urgency action". The redevelopment sequence of Shaanxi was changed from "Recent planning-II" to "Recent planning-I"; however, Guizhou's redevelopment sequence was just the opposite.

5. Conclusions and Policy Implications

This paper is the first study to provide a quantitative assessment of the basic information on the abandoned mine resource potential, the driving force, and the suitability of the redevelopment conditions and to put forward a priority list of abandoned mine redevelopment from the provincial perspective; this provides scientific foundation references for rational abandoned mine redevelopment industry distribution and regional eco-environment protection in the future.

5.1. Conclusions

(1) As for the theoretical contribution, this paper first constructs a comprehensive evaluation index system with the outstanding characteristics of the abandoned coal mines and the moderate scope. Secondly, the normal cloud model used in this paper, which discarded the traditional concept of membership but integrated the fuzziness and randomness of the indicators, provides a simple and reliable method for quantitative evaluation. This study evaluates the redevelopment potential of provincial abandoned mines from a more comprehensive perspective, which makes up for the deficiency of the current research in this field.

(2) For the problem of scientific decision making with regard to abandoned mine redevelopment, this article proposes the classification principles as "resource advance and coordinate development" and gives five types of potential levels and eight categories of redevelopment sequences. On this basis, it proposes policy emphasis suggestions for different redevelopment sequences; these suggestions have important value for practical redevelopment planning.

(3) The provinces with high potential for the redevelopment of abandoned mines in China are concentrated in the middle and eastern regions. The abandoned mines in most southwest provinces are not recommended for reuse, and the main focus should be on simple ecological restoration. The multi-driving force scenario simulation analysis shows that there is no obvious preference for abandoned mine development in most provinces of China, but Beijing, Anhui, Shaanxi, and Guizhou provinces should make further argumentation and analysis according to the demand preference.

(4) This paper provides a clear image of each province's AMRP in China from the macrolevel of regional demand and the economic development stage, which will guide the government to introduce effective strategic plans. However, the evaluation of the abandoned mine resource potential is still rough, and the redevelopment modes selection of abandoned mines needs to be further studied.

5.2. Policy Implications

A correct regional policy of abandoned mine redevelopment is derived from the accurate judgment of the stage and the level of development, or it would be blind or negative. Based on the above evaluation and the conclusions on the abandoned mine redevelopment potential, this paper provides the following policy implications and recommendations:

(1) For the "Urgent action" provinces, it is suggested that they conduct unprecedented experiments with AMR and establish the first comprehensive experimental areas. Considering that these provinces bear the burden of formulating the industrial policies and relevant standards for the other provinces, the government would need to carry out a "carrot and stick" policy in dealing with abandoned mine redevelopment. On the one side, penalties should be adopted to force these provinces to redevelop abandoned mines. On the other side, the government could provide some rewarding policies, such as financial subsidies, tax reductions or exemptions, special funds, etc., to encourage enterprises to try to reuse abandoned mine resources.

(2) For the "Recent planning" provinces, considering that the difficulty and cost of abandoned mine reutilization will increase if it is not planned earlier, the government is advised to provide strong supporting policies and incentive policies, such as increasing the input of the soft- and hardware in these areas, providing more subsidies, and building more relevant research institutes to support these provinces in participating in the redevelopment of the abandoned mines.

(3) For the "Medium-term planning" provinces, the provinces with better development conditions are encouraged to invest capital and technology in the provinces with higher resource potential. The government also can provide specific funds to support the research on the resource identification and value evaluation of the abandoned mines and further demonstrate the feasibility of abandoned mine redevelopment.

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Appendix A Appendix A

Table A1. Algorithm of forward normal cloud.

Given the Three Numerical Descriptors of One Factor (*Ex*, *En*, *He*) and the Specific Value x_i	
Step 1	Initially generate normal random $E_{ni}{}'$ with expectation *Ex* and variance *En*;
Step 2	Generate again normal random X_i with expectation *En* and variance *He*. The normal distribution function is expressed as *NORM*;
Step 3	Calculate $\mu_i = \exp\left[-(x_i - Ex)^2/2(E_{ni}{}')^2\right]$;
Step 4	The cloud drops drop(x, μ(x));
Step 5	Repeat steps 1–4 until n cloud drops are generated.

Table A2. The cloud parameters of indicators.

	I	II	III	IV	V
R_1	21.5; 18.2; 0.02	76.8; 28.8; 0.02	144.6; 28.8; 0.02	212.3; 28.8; 0.02	381.7; 115.1; 0.02
R_2	8.8; 7.5; 0.02	29.3; 9.9; 0.02	52.7; 9.9; 0.02	76.1; 9.9; 0.02	134.6; 39.7; 0.02
R_3	34.9; 29.7; 0.02	113.5; 37; 0.02	200.6; 37; 0.02	287.8; 37; 0.02	505.7; 148.1; 0.02
R_4	29.2; 24.8; 0.02	81.1; 19.3; 0.02	126.7; 19.3; 0.02	172.2; 19.3; 0.02	286.1; 77.4; 0.02
D_1	6; 5.1; 0.02	16.7; 4; 0.02	26.2; 4; 0.02	35.6; 4; 0.02	59.3; 16.1; 0.02
D_2	0.8; 0.7; 0.02	2.9; 1.1; 0.02	5.4; 1.1; 0.02	7.9; 1.1; 0.02	14.1; 4.3; 0.02
D_3	0.46; 0.39; 0.02	0.97; 0.05; 0.02	1.08; 0.05; 0.02	1.19; 0.05; 0.02	1.47; 0.19; 0.02
D_4	9.5; 8.1; 0.02	29.2; 8.6; 0.02	49.6; 8.6; 0.02	69.9; 8.6; 0.02	120.9; 34.6; 0.02
D_5	86.6; 73.5; 0.02	229.1; 47.5; 0.02	341.1; 47.5; 0.02	453.1; 47.5; 0.02	733.0; 190.2; 0.02
D_6	25.8; 21.9; 0.02	54.0; 2.0; 0.02	58.6; 2.0; 0.02	63.2; 2.0; 0.02	74.8; 7.9; 0.02
D_7	0.3; 0.2; 0.02	0.6; 0.1; 0.02	0.8; 01; 0.02	1.1; 0.1; 0.02	1.6; 0.4; 0.02
D_8	66.1; 14.4; 0.02	44.9; 3.6; 0.02	36.4; 3.6; 0.02	28.0; 3.6; 0.02	11.9; 10.1; 0.02
S_1	8186.6; 6952.5; 0.02	21,200.8; 4099.9; 0.02	30,856.1; 4099.9; 0.02	40,511.4; 4099.9; 0.02	64,649.7; 16399.7; 0.02
S_2	10,022.0; 8511.3; 0.02	22,087.4; 1735.3; 0.02	26,174.1; 1735.3; 0.02	30,260.8; 1735.3; 0.02	40,477.5; 6941.3; 0.02
S_3	0.4; 0.3; 0.02	1.3; 0.5; 0.02	2.4; 0.5; 0.02	3.5; 0.5; 0.02	6.3; 1.9; 0.02
S_4	1; 0.9; 0.02	2.7; 0.6; 0.02	4.1; 0.6; 0.02	5.6; 0.6; 0.02	9.1; 2.4; 0.02
S_5	22.5; 19.1; 0.02	46.8; 1.6; 0.02	50.6; 1.6; 0.02	54.5; 1.6; 0.02	64.0; 6.5; 0.02
S_6	0.4; 0.3; 0.02	0.9; 0.1; 0.02	1.1; 0.1; 0.02	1.4; 0.1; 0.02	2.0; 0.4; 0.02
S_7	1106.6; 939.8; 0.02	2399.4; 158.1; 0.02	2771.7; 158.1; 0.02	3144.0; 158.1; 0.02	4074.7; 632.3; 0.02
S_8	0.3; 0.2; 0.02	0.7; 0.2; 0.02	1.1; 0.2; 0.02	1.5; 0.2; 0.02	2.5; 0.7; 0.02
S_9	1.3; 1.1; 0.02	2.9; 0.2; 0.02	3.4; 0.2; 0.02	4.0; 0.2; 0.02	5.4; 1.0; 0.02
S_{10}	6.3; 5.3; 0.02	13.5; 0.8; 0.02	15.3; 0.8; 0.02	17.2; 0.8; 0.02	21.8; 3.2; 0.02
S_{11}	13.2; 11.2; 0.02	27.3; 0.8; 0.02	29.1; 0.8; 0.02	30.9; 0.8; 0.02	35.5; 3.1; 0.02
S_{12}	6.6; 5.6; 0.02	14.5; 1.1; 0.02	17.2; 1.1; 0.02	19.9; 1.1; 0.02	26.5; 4.5; 0.02

Table A3. Results by cloud model assessment approach.

Province	Dimension	I	II	III	IV	V
BJ	Resource potential	0.2300	0.0110	0.2915	0.0921	0.1788
	Driving force	0.4256	0.0113	0.1611	0.0153	0.1504
	Suitability	0.0556	0.1372	0.2652	0.0281	0.1847
HE	Resource potential	0.3381	0.2500	0.2957	0.1615	0.0901
	Driving force	0.2546	0.3754	0.1833	0.1674	0.1417
	Suitability	0.1932	0.3565	0.4016	0.1229	0.1127
SN	Resource potential	0.0000	0.0976	0.1242	0.2851	0.5582
	Driving force	0.1491	0.1895	0.1046	0.0046	0.3563
	Suitability	0.2992	0.4622	0.0999	0.2296	0.1101
IM	Resource potential	0.1189	0.0223	0.1844	0.0801	0.4951
	Driving force	0.1132	0.0031	0.0848	0.1477	0.6035
	Suitability	0.4856	0.2673	0.2545	0.0517	0.1108
LN	Resource potential	0.4620	0.0753	0.1134	0.3986	0.1336
	Driving force	0.0723	0.3580	0.5393	0.0536	0.1205
	Suitability	0.1296	0.3503	0.4500	0.1039	0.2016
JL	Resource potential	0.6169	0.4181	0.0310	0.0000	0.0157
	Driving force	0.3332	0.3398	0.4190	0.0058	0.0433
	Suitability	0.4925	0.5158	0.0554	0.0527	0.0331
HL	Resource potential	0.4541	0.0990	0.1467	0.0010	0.2968
	Driving force	0.2103	0.1512	0.3562	0.3833	0.1658
	Suitability	0.6231	0.4154	0.0360	0.0602	0.0476
JS	Resource potential	0.3032	0.1120	0.1303	0.1926	0.1997
	Driving force	0.4682	0.0547	0.0000	0.0078	0.3406
	Suitability	0.1138	0.0652	0.0698	0.0492	0.5590
AH	Resource potential	0.3651	0.0627	0.0001	0.0000	0.5702
	Driving force	0.5300	0.1441	0.0709	0.2835	0.1034
	Suitability	0.2045	0.4509	0.4251	0.0612	0.1154

Table A3. *Cont.*

Province	Dimension	I	II	III	IV	V
FJ	Resource potential	0.8383	0.1643	0.0076	0.0000	0.0075
	Driving force	0.7424	0.0422	0.1062	0.0718	0.0566
	Suitability	0.1372	0.2405	0.3931	0.3886	0.1961
JX	Resource potential	0.4678	0.2408	0.0975	0.1052	0.0488
	Driving force	0.5715	0.3079	0.0996	0.0003	0.0197
	Suitability	0.2575	0.8131	0.1364	0.0382	0.0449
SD	Resource potential	0.0321	0.4051	0.5738	0.0675	0.0904
	Driving force	0.3356	0.2060	0.1885	0.0126	0.2821
	Suitability	0.0872	0.2086	0.2079	0.1072	0.5436
HA	Resource potential	0.0857	0.6501	0.3366	0.0303	0.0590
	Driving force	0.3976	0.2468	0.0221	0.0378	0.2001
	Suitability	0.2345	0.2630	0.2807	0.2292	0.1887
HB	Resource potential	0.7609	0.0584	0.1190	0.0071	0.0179
	Driving force	0.5855	0.1201	0.3400	0.0082	0.0304
	Suitability	0.1611	0.3802	0.3655	0.2302	0.1236
HN	Resource potential	0.4824	0.0942	0.0789	0.2784	0.0963
	Driving force	0.4692	0.4624	0.1305	0.0031	0.0233
	Suitability	0.1705	0.4573	0.3990	0.1532	0.1030
GX	Resource potential	0.4755	0.3111	0.0767	0.0001	0.0173
	Driving force	0.5085	0.3900	0.0041	0.0013	0.0114
	Suitability	0.4335	0.6302	0.0374	0.0269	0.0243
CQ	Resource potential	0.8465	0.0832	0.0000	0.0001	0.1084
	Driving force	0.5614	0.1172	0.1811	0.1766	0.0771
	Suitability	0.2138	0.4849	0.4004	0.0759	0.0913
SC	Resource potential	0.5463	0.0467	0.0795	0.2324	0.1594
	Driving force	0.3903	0.3557	0.2034	0.0222	0.0300
	Suitability	0.3520	0.4013	0.1763	0.2614	0.0962
GZ	Resource potential	0.5063	0.1045	0.0002	0.0150	0.3408
	Driving force	0.1624	0.3979	0.3664	0.0983	0.0605
	Suitability	0.7527	0.2033	0.0457	0.0391	0.0219
YN	Resource potential	0.6190	0.2821	0.0041	0.0000	0.0251
	Driving force	0.3336	0.4213	0.0943	0.0162	0.0242
	Suitability	0.6765	0.3078	0.0571	0.0317	0.0308
SX	Resource potential	0.0002	0.2657	0.3346	0.4000	0.2104
	Driving force	0.1610	0.2595	0.3355	0.2072	0.1691
	Suitability	0.2668	0.7768	0.0987	0.0385	0.0741
GS	Resource potential	0.4463	0.2817	0.3526	0.0098	0.0445
	Driving force	0.2492	0.4297	0.0335	0.1375	0.2209
	Suitability	0.7095	0.1722	0.0930	0.0709	0.0703
QH	Resource potential	0.7219	0.2033	0.0004	0.0000	0.0079
	Driving force	0.1193	0.0800	0.3509	0.0312	0.3835
	Suitability	0.5804	0.2369	0.0342	0.0308	0.0587
NX	Resource potential	0.3842	0.0279	0.0027	0.1821	0.4649
	Driving force	0.1572	0.0500	0.0942	0.3049	0.4808
	Suitability	0.3847	0.3974	0.0396	0.1133	0.1633
XJ	Resource potential	0.1189	0.3967	0.1828	0.3452	0.1303
	Driving force	0.1325	0.0094	0.0797	0.1214	0.5045
	Suitability	0.6822	0.1450	0.0677	0.0153	0.0568

Table A4. Comparison scale of analytic hierarchy process.

Factor of Preference	Importance Definition
1	Equal importance
3	Moderate importance of one over another
5	The strong or essential importance of one over another
7	Very strong or demonstrated importance of one over another
9	The extreme importance of one over another
2, 4, 6, 8	Intermediate values

Table A5. Listing and abbreviations of the provincial-level administrative units.

Provinces	Abbreviation	Provinces	Abbreviation
Beijing	BJ	Hunan	HN
Tianjin	TJ	Guangdong	GD
Heibei	HE	Guangxi	GX
Shaanxi	SX	Hainan	HI
Inner Mongolia	IM	Chongqing	CQ
Liaoning	LN	Sichuan	SC
Jilin	JL	Guizhou	GZ
Heilongjiang	HL	Yunnan	YN
Henan	HA	Shanxi	SN
Jiangsu	JS	Gansu	GS
Zhejiang	ZJ	Qinghai	QH
Anhui	AH	Ningxia	NX
Fujian	FJ	Xinjiang	XJ
Jiangxi	JX		
Shandong	SD		
Hubei	HB		

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