Discussion on the Copper Resource Reserve Scale and the Layout of Reserve Base in China

Jianbo Yang\textsuperscript{a} and Qunyi Liu\textsuperscript{b,*}

Institute of mineral resources, Chinese Academy of Geological Sciences,
No. 26 Baiwanzhuang Street, Xicheng District, Beijing 100037, China

\textsuperscript{a}yangjianbo@cags.ac.cn, \textsuperscript{b}liuqunyi@cags.ac.cn

\textbf{Keywords:} Copper resources; Reserve scale; Mineral resource land reserve; Base layout

\textbf{Abstract:} This article measured the reasonable scale of copper resource land reserves in China using the safety stock theory based on the commodity safety stock theory and analyzed the reasonable scale under different circumstances. In combination with the current situation and future development trend of China’s copper industry and through analysis, the appropriate scale of copper resource land reserves in China is between 5–6 million tons for future use. The analytic hierarchy process is used to establish the evaluation model of the spatial layout of copper resource land reserves and make a comprehensive evaluation of mineral resource land reserves in 30 provinces (cities and districts). The study shows that among these provinces, Yunnan, Jiangxi, Inner Mongolia, Anhui, and Gansu contain the most amount of copper resource land reserves. Therefore, copper mines (deposits) in these five provinces (regions) can be selected and included in the mineral resource land reserve plan. Tibet and Xinjiang have huge copper reserves and good prospecting potential, but some mines in such provinces cannot be used because the natural conditions are unfavorable. Therefore, appropriate copper mines (deposits) should be selected and included in the long-term mineral resource land reserve plan.

1. Preface

Copper is one of the major minerals that is urgently required in China. Among China’s existing 96 sectors, approximately 90 sectors are related to copper. However, the copper resources in China are relatively scarce with China’s copper reserves ranking only 7th in the world, and its per capita share is far below the world average. In 2015, China’s mined copper production was 1.73 million tons, which could only meet 15% of the domestic requirement, and the total requirement was 11.35 million tons (refined copper). Thus, considering China’s secondary copper supply situation, China had an external dependence on copper of more than 70%. As the demand for refined copper grows fast and the dependence on foreign countries rises year by year, the difficulty in ensuring the security of copper resource supply is increasing. Therefore, it is particularly important to strengthen the strategic reserve of copper resources.

Copper reserves include copper product reserves and mineral resource land reserves. The mineral resource land reserve plan refers to the land that contains mineral resources, and the purpose of the plan is to ensure the security of mineral resources supply\cite{1}. The “13th Five-Year Plan” of the Ministry of Land and Resources of the People’s Republic of China has been clearly put forward “to delineate the reserve area of mineral resources and include the mining area that has an important value to the national economy into the reserve management.” In accordance with the plan, the mineral resource land reserves can be divided into working reserves, control reserves, and strategic reserves. In this paper, the research object is the extent of strategic reserve and the spatial layout of reserve bases, the main body of the reserve is the state, and the object reserved is the copper resource itself.

2. Study on the scale of mineral resource land reserves

2.1 Method for evaluating the scale of mineral resource land reserves

Safety stock denotes the timeframe over which stock exceeds consumers’ actual demand and as such provides a buffer to demand uncertainty\cite{2-3}. The purpose of safety stock is to predict and respond to the possible occurrence of uncertain risks, mainly in the form of instability and...
uncertainty of demand [4-5]. An appropriate scale of safety stock can minimize, and even completely eliminate, the future influence of uncertainty on the normal production of enterprises. Therefore, while meeting consumer demand, safety stock can reduce costs and strengthen enterprise competitiveness [6].

The main factors that influence the scale of actual safety stock include the level of consumer service, the uncertainty of consumer demand and the instability of lead time.

Level of consumer service: a measure of the ratio between the order quantity that can be met within a period of time and the total orders within this period time [7-8].

Uncertainty of consumer demand: a measure of the standard deviation of consumers’ actual consumption quantity demanded.

Instability of lead time: the time interval between the placing of an order to the goods’ arrival at the warehouse. The longer the interval is, the larger the scale of safety stock is, and vice versa.

The computational formula to determine safety stock is as follows [9]:

\[
SS = z \sqrt{\sigma_d^2(L) + \sigma_z^2(d)^2}
\]

(1)

Here, \(SS\) refers to the actual safety stock; \(L\) refers to the mean value of lead time; \(d\) refers to the consumers’ daily demand for the product; \(z\) refers to the safety factor determined by the level of service; \(\sigma_d\) refers to the standard deviation of the consumers’ daily demand; and \(\sigma_L\) refers to the standard deviation of lead time \(L\).

2.2 Study on the spatial layout of copper resource land reserves in China

Similar to the commodity stock of an enterprise, a state’s mineral resource land reserves are of equal significance. This article measured our country’s copper resource land reserves by means of enterprise safety stock theory. Thus, the parameters in Formula (1) can be substituted as follows: \(SS\) refers to the extent of mineral resource land reserves; \(\bar{L}\) refers to the mean value of the construction and commissioning period; \(\bar{d}\) refers to the future resource consumption demand; \(z\) refers to the safety factor influenced by the satisfaction degree of production supply and consumption demand; \(\sigma_d\) refers to the standard deviation of annual resource consumption demand \(d\); and \(\sigma_L\) refers to the standard deviation of the construction and commissioning period \(L\).

According to our country’s anticipated demand for copper in the future taking into account a construction period of 3 to 5 years and the mineral resource reserves used to meet the short supply overseas, the extent of our country’s copper resource land reserves under different scenarios was determined (Table 1). By taking into account the extent of copper resource land reserves in China under different safety factor scenarios and timeframes, the future extent of copper resource land reserves in China was calculated to be between 5 to 6 million tons.

<table>
<thead>
<tr>
<th>Year</th>
<th>Safety factor 0.50</th>
<th>Safety factor 0.80</th>
<th>Safety factor 1.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>286</td>
<td>457</td>
<td>571</td>
</tr>
<tr>
<td>2016</td>
<td>298</td>
<td>476</td>
<td>596</td>
</tr>
<tr>
<td>2017</td>
<td>312</td>
<td>500</td>
<td>625</td>
</tr>
<tr>
<td>2018</td>
<td>323</td>
<td>517</td>
<td>647</td>
</tr>
<tr>
<td>2019</td>
<td>336</td>
<td>537</td>
<td>672</td>
</tr>
<tr>
<td>2020</td>
<td>344</td>
<td>551</td>
<td>689</td>
</tr>
</tbody>
</table>
3. Method for evaluating mineral resource land reserves

The study of the spatial distribution of copper mine land reserves mainly considers the mineralization conditions of copper mines in China, as well as the industrial policies and environmental policies in the main distribution areas of copper resources. The mineral land reserve evaluation method is an appropriate means used to analyze and obtain the spatial distribution of copper mine land reserve bases in China’s main provinces. In view of the numerous factors affecting mineral resource land reserves, this paper selects the analytic hierarchy process (AHP) that is suitable for analyzing complex factors.

The AHP is a combination of qualitative and quantitative methods, which makes the complex decision-making system hierarchical and establishes a model by comparing the importance of various associated factors. It is mainly used to analyze the nature and influencing factors of complex problems and the internal relations among influencing factors. AHP semi-quantitatively enables the mathematization of the decision-making process; thus, it is especially applicable for analyses in which it is difficult to directly and accurately measure the decision results[10]. The method was first proposed by Satty of the United States[11].

In the analysis of copper resource land reserves, the influencing factors are complex, diverse, and interactional. Moreover, it is difficult to perform a quantitative analysis of the mutual comparison among these factors. Therefore, it is necessary to transform semi-quantitative and semi-qualitative problems into quantitative problems. In this paper, the decision-making system of copper resource land reserves is anatomized layer-by-layer. By comparing the importance of the different factors layer-by-layer, the basis for the final decision-making is obtained.

4. Study on the spatial layout of copper resource land reserves in China

(1) Evaluation model of the spatial layout of copper resource land reserves

In view of the spatial layout of mineral resource land reserves and during the construction of the indicator system, the main considerations should be as follows: the necessity of mineral resource land reserves, manifested as policy indicators, environmental indicators, and regional geography indicators; and the feasibility of mineral resource land reserves, manifested as geological and economic indicators of the resources. According to the basic principles of the evaluation indicator system construction and the main basis of indicator selection, the evaluation indicator system of the spatial layout of copper resource land reserves constructed in this paper includes five second grade indicators (Table 2).

<table>
<thead>
<tr>
<th>First grade indicators</th>
<th>Second grade indicators</th>
<th>Third grade indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>K5 mineral resource land reserve</td>
<td>Z2 policy</td>
<td>Z1 economic and industrial policy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Z2 environmental policy</td>
</tr>
<tr>
<td></td>
<td>Q3 regional geography</td>
<td>Q1 human geography</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Q2 traffic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Q3 regional industrial structure</td>
</tr>
<tr>
<td></td>
<td>D5 geology</td>
<td>D1 surrounding rock conditions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D2 buried depth</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D3 orebody scale</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D4 grade</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D5 hydrogeological conditions</td>
</tr>
<tr>
<td></td>
<td>H2 environmental factors</td>
<td>H1 regional ecological environment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>H2 regional water environment</td>
</tr>
<tr>
<td></td>
<td>J5 economy</td>
<td>J1 regional copper resource consumption</td>
</tr>
<tr>
<td></td>
<td></td>
<td>J2 regional copper net input of mines</td>
</tr>
</tbody>
</table>
Z1 economic industrial policy: Copper resources industry policy determines the direction of the development of copper resources and has a guiding role in copper reserves. Under the industrial policy of national and regional low carbon emission and environmental protection, copper resource land reserves should be compatible with the economic and industrial policies.

Z2 environmental policy: The rational layout of copper resource development and reserves is affected by environmental policy changes.

Q1 human geography: Climate changes cause a periodic halt in the production of some mines; the frequency of major natural disasters also has a certain impact on copper production and consumption, and different social humanistic environments have a special impact on the development and reserves of copper resources.

Q2 transportation: there are some differences between China’s major copper supply centers and consumption centers. As an important bulk commodity, its transportation time and price have an impact on the stable supply of copper resources.

Q3 regional industrial structure: The adjustment of industrial structure has a promotion (or inhibition) role in the development and utilization of copper resources.

D1 surrounding rock conditions: The conditions mainly affect the difficulty level of the exploitation of copper resources in a region, as well as the development costs. Moreover, they have a certain late transformation role in the amount of resources. The average surrounding rock conditions of major mines in the region are taken as a calculation indicator.

D2 burial depth: This depth determines the difficulty level of the exploitation of copper resources in a region and the development costs to some extent. The average burial depth of major mines in the region is taken as a calculation indicator.

D3 ore body size: This size affects the selection of mining layout and mining methods. The size of major ore deposits in the region is taken as a calculation indicator.

D4 grade: It determines the rational use and industrial value of copper resources. The average grade of major mines in the region is taken as a calculation indicator.

D5 hydrogeological conditions: It is one of the important factors that determine the underground mining method and cost.

H1 regional ecological environment: It affects the exploration, development, and utilization of copper resources, and the development of copper resources should not be performed in scenic areas, protected areas, and ecologically fragile areas. It evaluates the ecological vulnerability in various regions based on the national environmental functional district planning.

H2 regional water environment: It mainly evaluates the influence of copper mining, smelting, and processing on water resources and the influence of copper reserves on groundwater and surface water.

J1 regional copper consumption: The refined copper production of a province (city and district) is taken as the calculation indicator of copper resource consumption.

J2 regional copper net input of mines: The copper (metal) production and the refined copper production of the mines in the provinces are considered as a calculation indicator.

J3 regional copper production capacity of mines, J4 regional available reserves of copper resource, and J5 regional copper resource potential have a certain impact on mineral resource land reserves. They are calculated according to the data released by the National Bureau of Statistics and China Nonferrous Metals Industry Association.

(2) Construction of the original data matrix

The original data matrix was formed according to the raw score of each indicator of the mineral source land spatial layout evaluation model (1–4 points). See Table 1 for the scoring principles. When it is difficult to determine the value of individual indicators for a province, the average is taken.
(3) Determination of weight
When the AHP is used to calculate the weight of each factor, the analysis steps are as follows:

1. Establishment of a hierarchy model

In the study of a copper resource land reserve layout, different evaluation indicators are selected to maximize the benefit of copper resource reserve layout decisions, that is, the selected location of reserves should be reasonable and scientific. There are five main indicators to consider and the hierarchical structure model is established (Table 3).

2. Construction of a three-scale comparison matrix

According to expert advice and expert scoring, the importance of two indicators is compared based on the evaluation model, and a three-scale comparison matrix, in which:

\[ a_{ij} \]

- Factor \( i \) is more important than factor \( j \)
- Factor \( i \) is equal important to factor \( j \)
- Factor \( i \) is less important than factor \( j \)

The three-scale comparison matrix for the second grade indicators of mineral resource land reserves is as follows:

\[
K = (k_{ij})_{5\times5} = \begin{bmatrix}
1 & 2 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 \\
2 & 2 & 1 & 2 & 0 \\
2 & 2 & 0 & 1 & 0 \\
2 & 2 & 2 & 2 & 1 \\
\end{bmatrix}
\]

Similarly, the comparison matrix for the second grade indicators can be constructed: \( Z_{2\times2}, Q_{3\times3}, D_{5\times5}, H_{2\times2}, J_{5\times5} \)

\[
Z = (z_{ij})_{2\times2} = \begin{bmatrix}
1 & 0 \\
2 & 1 \\
\end{bmatrix}
\]

\[
Q = (q_{ij})_{3\times3} = \begin{bmatrix}
1 & 0 & 0 \\
2 & 1 & 0 \\
2 & 2 & 1 \\
\end{bmatrix}
\]

\[
D = (d_{ij})_{5\times5} = \begin{bmatrix}
1 & 0 & 0 & 0 & 2 \\
2 & 1 & 2 & 0 & 2 \\
2 & 0 & 1 & 0 & 2 \\
2 & 2 & 2 & 1 & 2 \\
0 & 0 & 0 & 0 & 1 \\
\end{bmatrix}
\]

\[
H = (h_{ij})_{2\times2} = \begin{bmatrix}
1 & 2 \\
0 & 1 \\
\end{bmatrix}
\]

\[
J = (j_{ij})_{3\times5} = \begin{bmatrix}
1 & 2 & 2 & 0 & 0 \\
0 & 1 & 2 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 \\
2 & 2 & 2 & 1 & 2 \\
2 & 2 & 2 & 0 & 1 \\
\end{bmatrix}
\]

3. Computation of the importance degree ranking index

The importance degree ranking index \( r_i \) of \( i \):

\[
r_i = \sum_{j=1}^{5} a_{ij}
\]
Then the minimum importance degree ranking index $r_{\text{min}}$. In this paper, $r_{\text{min}} = 1$.

4. Construction of the indirect judgment matrix

In indirect judgment matrix B, element $b_{ij}$ is:

$$b_{ij} = \begin{cases} 
(r_i - r_j) / r_{\text{min}} + 1 & (r_i \geq r_j) \\
[(r_j - r_i) / r_{\text{min}} + 1]^{-1} & (r_i < r_j)
\end{cases}$$

(2)

5. Computation of the antisymmetric matrix

The antisymmetric matrix of the indirect judgment matrix B is $C = (c_{ij})_{5\times5}$, where

$$c_{ij} = \log b_{ij}$$

(3)

6. Computation of the optimal transfer matrix

The optimal transfer matrix of antisymmetric matrix is $D = (d_{ij})_{5\times5}$, where

$$d_{ij} = \frac{1}{5} \sum_{k=1}^{5} (c_{ik} - c_{jk})$$

(4)

7. Establishment of quasi optimal consistent matrix

The quasi optimal consistent matrix of the indirect judgment matrix B is $B^* = (b_{ij}^*)_{5\times5}$, where

$$b_{ij}^* = 10^{d_{ij}}$$

(5)

8. Normalization of the weights

The normalization of the weights is represented by the following formula (6):

$$k_i = (\sum_{i=1}^{5} b_{ij}^*)^{-1}$$

(6)

(4) Results of mineral resource land layout evaluation
<table>
<thead>
<tr>
<th>Name of indicators/Scoring standards</th>
<th>4 Points</th>
<th>3 Points</th>
<th>2 Points</th>
<th>1 Point</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Z1 economic and industrial policy</strong></td>
<td>Pillar industry</td>
<td>Important industry</td>
<td>Ordinary industry</td>
<td>Limited industry</td>
</tr>
<tr>
<td><strong>Z2 environmental policy</strong></td>
<td>Encouraged development</td>
<td>Moderate development</td>
<td>Maintain the existing scale</td>
<td>Restricted development</td>
</tr>
<tr>
<td><strong>Q1 human geography</strong></td>
<td>Good conditions</td>
<td>Relatively good conditions</td>
<td>General conditions</td>
<td>Bad conditions</td>
</tr>
<tr>
<td><strong>Q2 traffic</strong></td>
<td>Convenient</td>
<td>Good</td>
<td>Average</td>
<td>Poor</td>
</tr>
<tr>
<td><strong>Q3 regional industrial structure</strong></td>
<td>No adjustment</td>
<td>Slight adjustment</td>
<td>Adjustment</td>
<td>Great adjustment</td>
</tr>
<tr>
<td><strong>D1 surrounding rock conditions</strong></td>
<td>Good</td>
<td>Relatively good</td>
<td>Average</td>
<td>Complex</td>
</tr>
<tr>
<td><strong>D2 buried depth</strong></td>
<td>Strip mine</td>
<td>Shallow</td>
<td>Relatively shallow</td>
<td>Deep</td>
</tr>
<tr>
<td><strong>D3 orebody scale</strong></td>
<td>Ultra-large</td>
<td>Large</td>
<td>Medium</td>
<td>Small</td>
</tr>
<tr>
<td><strong>D4 grade</strong></td>
<td>High</td>
<td>Relatively high</td>
<td>Average</td>
<td>Low</td>
</tr>
<tr>
<td><strong>D5 hydrogeological conditions</strong></td>
<td>Extremely low</td>
<td>low</td>
<td>Average</td>
<td>Abundant</td>
</tr>
<tr>
<td><strong>H1 regional ecological environment</strong></td>
<td>Slightly vulnerable</td>
<td>Mildly vulnerable</td>
<td>Moderately vulnerable</td>
<td>Severely vulnerable</td>
</tr>
<tr>
<td><strong>H2 regional water environment</strong></td>
<td>Abundant water, less pollution</td>
<td>Abundant water, pollution</td>
<td>Not abundant, less pollution</td>
<td>Not abundant, serious pollution</td>
</tr>
<tr>
<td><strong>J1 regional copper resource consumption</strong></td>
<td>Over 15% of the total national consumption</td>
<td>7%–15% of the total national consumption</td>
<td>3%–7% of the total national consumption</td>
<td>Less than 3% of the total national consumption</td>
</tr>
<tr>
<td><strong>J2 regional copper net input of mines</strong></td>
<td>Net output accounts for over 50% of production</td>
<td>Net output accounts for less 50% of production</td>
<td>Net output accounts for less 100% of production</td>
<td>Net output accounts for over 100% of production</td>
</tr>
<tr>
<td><strong>J3 regional copper production capacity of mines</strong></td>
<td>Over 15% of national share</td>
<td>7%–15% of national share</td>
<td>3%–7% of national share</td>
<td>Less than 3% of national share</td>
</tr>
<tr>
<td><strong>J4 regional available reserves of copper resource</strong></td>
<td>Over 15% of national share</td>
<td>7%–15% of national share</td>
<td>3%–7% of national share</td>
<td>Less than 3% of national share</td>
</tr>
<tr>
<td><strong>J5 regional copper resource potential</strong></td>
<td>Over 15% of national share</td>
<td>7%–15% of national share</td>
<td>3%–7% of national share</td>
<td>Less than 3% of national share</td>
</tr>
</tbody>
</table>
According to the scores and weights of indicators for each province, the evaluation results for the spatial layout of mineral resource land reserve are obtained (Table 4).

According to the scores, Yunnan, Jiangxi, Inner Mongolia, Anhui and Gansu rank the top five, and the national industrial policies have classified the provinces, as important non-ferrous-metal industrial bases. Therefore, appropriate copper mines (deposits) in these areas can be selected and included in the mineral resource land reserve plan. Tibet and Xinjiang have a large amount of copper reserves and good potential for mineral prospecting. The government strongly supports the economic development of ethnic autonomous areas. However, the ecological and environmental conditions of the two places are poor. Appropriate copper mines (deposits) in these areas can be selected and included in the long-term mineral resource land reserve plan.

<table>
<thead>
<tr>
<th>Province</th>
<th>Region</th>
<th>Scores</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yunnan</td>
<td>Southwest China</td>
<td>3.74</td>
<td>1</td>
</tr>
<tr>
<td>Jiangxi</td>
<td>East China</td>
<td>3.73</td>
<td>2</td>
</tr>
<tr>
<td>Inner Mongolia</td>
<td>North China</td>
<td>3.23</td>
<td>3</td>
</tr>
<tr>
<td>Anhui</td>
<td>East China</td>
<td>3.14</td>
<td>4</td>
</tr>
<tr>
<td>Gansu</td>
<td>Northwest China</td>
<td>3.08</td>
<td>5</td>
</tr>
<tr>
<td>Tibet</td>
<td>Northwest China</td>
<td>2.64</td>
<td>6</td>
</tr>
<tr>
<td>Hubei</td>
<td>Central South China</td>
<td>2.63</td>
<td>7</td>
</tr>
<tr>
<td>Xinjiang</td>
<td>Northwest China</td>
<td>2.63</td>
<td>7</td>
</tr>
<tr>
<td>Sichuan</td>
<td>Southwest China</td>
<td>2.34</td>
<td>9</td>
</tr>
<tr>
<td>Qinghai</td>
<td>Northwest China</td>
<td>2.34</td>
<td>9</td>
</tr>
</tbody>
</table>

5. Summary

This article measured the reasonable scale of copper resource land reserves in China using the safety stock theory based on the commodity safety stock theory and analyzed the reasonable scale under different circumstances. In combination with the current situation and future development trend of China’s copper industry and through analysis, the appropriate scale of copper resource land reserves in China is between 5–6 million tons for future use.

In this paper, the AHP is used to construct the evaluation model that includes 5 second-grade indicators (i.e., policy indicator, environmental indicator, regional geography indicator, geological indicator, and economic indicator) and 17 third-grade indicators specific to the spatial layout of mineral resource land reserves. Moreover, AHP is used to obtain the weight of each indicator in order to make a comprehensive evaluation of the copper resource land reserves in 30 provinces in China. The study shows that among these provinces, Yunnan, Jiangxi, Inner Mongolia, Anhui, and Gansu contain the most amount of copper resource land reserves. Therefore, copper mines (deposits) in these five provinces (regions) can be selected and included in the mineral resource land reserve plan. Tibet and Xinjiang have huge copper reserves and good prospecting potential, but some mines in such provinces cannot be used because the natural conditions are unfavorable. Therefore, appropriate copper mines (deposits) should be selected and included in the long-term mineral resource land reserve plan.

References


