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Regional Distribution and Sustainable Development Strategy of Mineral Resources in China

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Abstract: This paper summarizes the distribution and production layout of the major mineral resources in China, including coal, iron ore, copper and bauxite, from a national perspective. It also identifies the incompatibility between the mineral resources distribution and regional economic development. Significant issues with China′s mineral resource industry cause challenges for the sustainable development of both the mining industry and the national socio-economy. The sustainability of regional mineral resources and the environmental pollution by mining in the western China were also analyzed. Results show that the distribution of China's mineral resources is misaligned with its regional layout of economic development. China's mineral resources have been over-exploited, and the mineral resources production in the eastern China is unsustainable. The continuously expanding production of mineral resources in the western China has heavily endangered the ecological environment. We propose strategies to boost the sustainable development of mineral resources, including measures to accelerate economic development and enhance the sustainability of domestic mineral resources. We also offer suggestions for scientifically planning the mineral resource prospecting and exploitation and regional economic layout, as well as for proactively undertaking industry transfer in the eastern China and raising the environmental benchmark requirements for the mineral industry in the central and western China.

Keywords: mineral resources; resources distribution; sustainable development; strategy research

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1 Introduction

The sustainable development of mineral resources relates to the sustainable development of the state economy, society and environment. Therefore, it has been widespread concern in academic circles. From the perspectives of research theories, methods and technologies, early researches on the sustainable development of mineral resources were mainly macro-qualitative studies focused on concepts, contributing factors and countermeasures (Below, 1993; Raymond, 1994; Gavin, 2006). For example, Wellmer and Becker-Platen (2002) proposed that from a macro perspective, sustainable development requires rational utilization of mineral resources and maintenance of the balance among the economy, ecological environment and social fairness. As the theories and methodologies advanced, the research perspectives diversified. The methodologies evolved from qualitative studies to modeling, systematic and quantitative studies. Stewart (1992) and Petrie *et al*. (2002; 2007) formulated a decision-making procedure for the sustainable development of mineral resources, which employed systems engineering and computer technology.

As for the sustainable development of mineral resources, researchers in different countries focused their attention on different problems, as countries differ in development phases and mineral resources. For countries rich in mineral resources, such as Australia, South

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Africa, Chili and Peru, the researchers have focused on the studies of the ′resources curse′ and the influence of the mineral industry on the economy. Mudd *et al*. (2009; 2010) and Prior *et al*. (2012) studied the continuous prosperity of mineral industry in Australia and its impact upon Australia′s economy. Nayak (2012) investigated the impact of mineral industry development upon the environment and society in Orissa, India. Studies regarding the impact of mineral resources use on environment and ecology are popular in industrialized Euro-American countries. Stefan *et al*. (2008) analyzed the Resource-Environment-Economy model for the sustainable use of resources in Europe and suggested a quantitative evaluation of the impact on the environment. Gyozo (2009) focused on environmental issues in Europe that stemmed from the development of the mineral industry and came up with methods to assess the associated environmental risks.

The studies in China mainly cover the sustainable use of mineral resources, the impact of mineral resources upon the environment and economy and the ′resources curse′ and ′mine in crisis ′ theories. The spatial scales of these studies range from provinces rich in mineral resources to important mineral resources areas and specific mines. For example, Duan and Sun (2011) and Ye *et al*. (2012) studied the sustainable use of mineral resources in Hebei and Jiangxi provinces, respectively, which are two provinces rich in mineral resources. These studies analyzed the measurement indices and issues regarding sustainable exploitation and utilization by examining the problems of overexploitation, insufficient follow-up support, low utilization efficiency and environment pollution. Jiang *et al*. (2011) studied the sustainable development strategies for lead-zinc mines and analyzed the current status of mineral resource uses, taking Laochang mine in Zhuang Autonomous Region of Guangxi as a case, which is in crisis. After China′s Western Development Strategy was put into operation, more and more studies on sustainable resource use, the ecological environment and ecological compensation have surfaced. By testing an empirical hypothesis, Zhang *et al*. (2011) discussed the impact of mineral resources exploitation in Xinjiang upon the regional economy. Hu (2012) and Wang and Li (2012) expounded the sustainable development of the western China from the perspectives of mineral resources sustainability, the ecological environment and ecological compensation. Other scholars raised the idea of regional ecological safety and the corresponding principles and methods for the sustainable management of mineral resources (Li *et al*., 2004; Ma *et al*., 2004; Yang *et al*., 2004).

While it is important to recognize the general regional distribution of mineral resources throughout China, because which is significant to mineral sustainable development. Accordingly, based on the data of statistical yearbooks from authorities such as National Bureau of Statistics of China, and China Nonferrous Metals Industry Association (Because of the limitation of the data, this study does not include such regions as Hong Kong, Macao and Taiwan), this study summarizes the basic reserve and production distribution of major mineral resources, such as coal, iron, copper and bauxite, in China and then analyzes the incompatibility of the mineral resources distribution with regional economic development. This study also notes the issues that need to be resolved by a sustainable development strategy and regarding proposals.

2 Mineral Resources Distribution

The regional distribution of mineral resources is an important consideration for the sustainable development of mineral resources. China is abundant in mineral resources; the production of coal accounts for approximately 80% of the total energy output, and iron ore, copper and bauxite constitute approximately 90% of the total metal output (NBSC, 2012a). Distribution of basic reserve and production of these four mineral resources will be adopted as indicators to analyze the regional distribution of mineral resources in China.

2.1 Coal

In China, coal has identical distribution and production patterns and is mainly concentrated in some provinces (regions) in Northwest China and North China (Fig. 1). In 2011, the basic coal reserve was 2.157×10^{11} t, among which 68% was distributed in Shanxi, Inner Mongolia, Xinjiang and Shaanxi (Fig. 1, Fig. 2). This distribution establishes that the western China contains more coal than the eastern China, and the northern China contains more coal than the southern China. The production structure of coal in China in 2011 demonstrates that the total output was 3.52×10^9 t, of which the output from Inner Mongolia, Shanxi, Shaanxi and Henan constituted

72% (Fig. 2). The distribution of coal in China is consistent with its production layout more or less. However, inconsistencies exist: Shaanxi Province has 5% of the basic reserve but produces 12% of the total coal in China; Shanxi has 39% of the basic reserve but only produces 25% of the total coal; and Xinjiang has 7% of the basic reserve but produces only 3% of the total coal.

2.2 Iron ore

China is abundant in highly concentrated iron ore. In 2011, the basic reserve of iron ore in China reached 1.94 × 10^{10} t, 56% of which was distributed in three provinces, Liaoning, Hebei and Sichuan (Fig. 3, Fig. 4), which are also the largest iron ore-producing provinces. In 2011, China produced 1.327 × 10^{9} t of iron ore, among which 67% was from Hebei, Liaoning and Sichuan provinces (Fig. 4). Similar to China′s coal production, there are inconsistencies in the iron-ore production as well: Hebei produces 45% of the iron ore, but it only has 14% of the basic reserve, and Liaoning Prov-

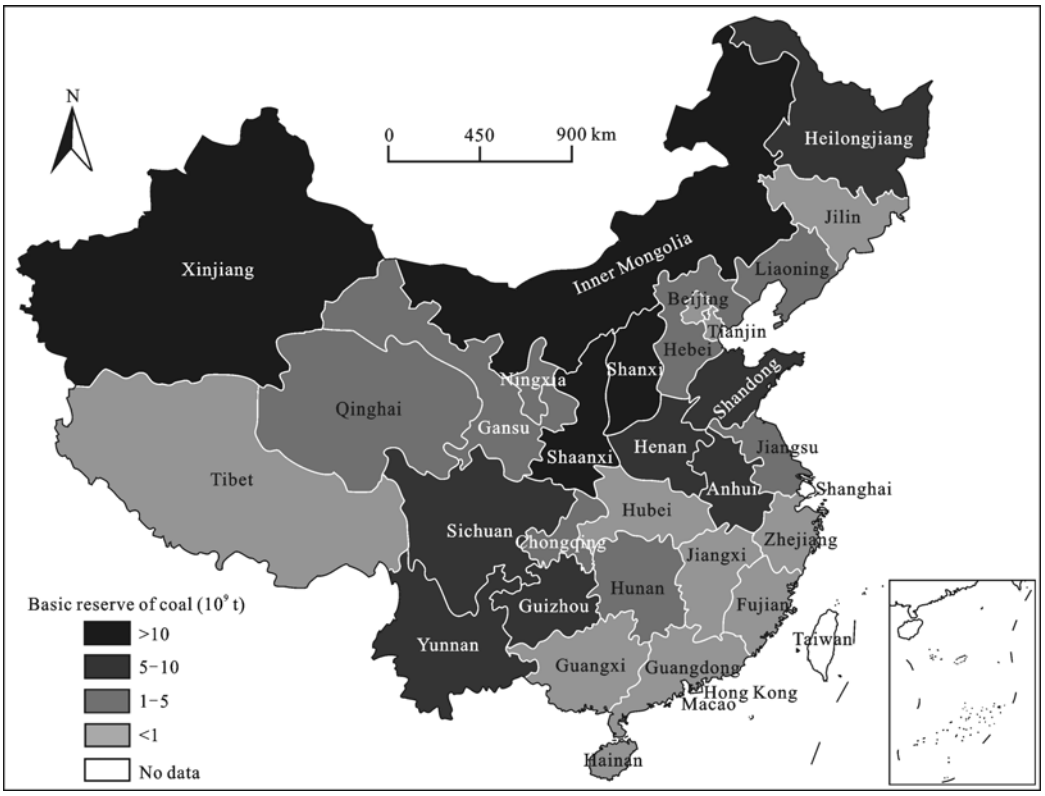

Fig. 1 Coal distribution in China in 2011 (NBSC, 2012a)

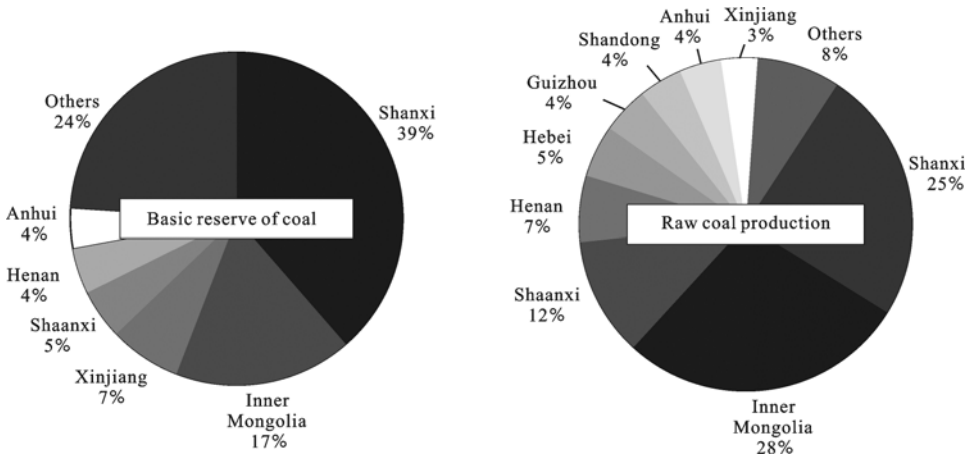

Fig. 2 Basic reserve and production distribution of coal in China in 2011 (NBSC, 2012a)

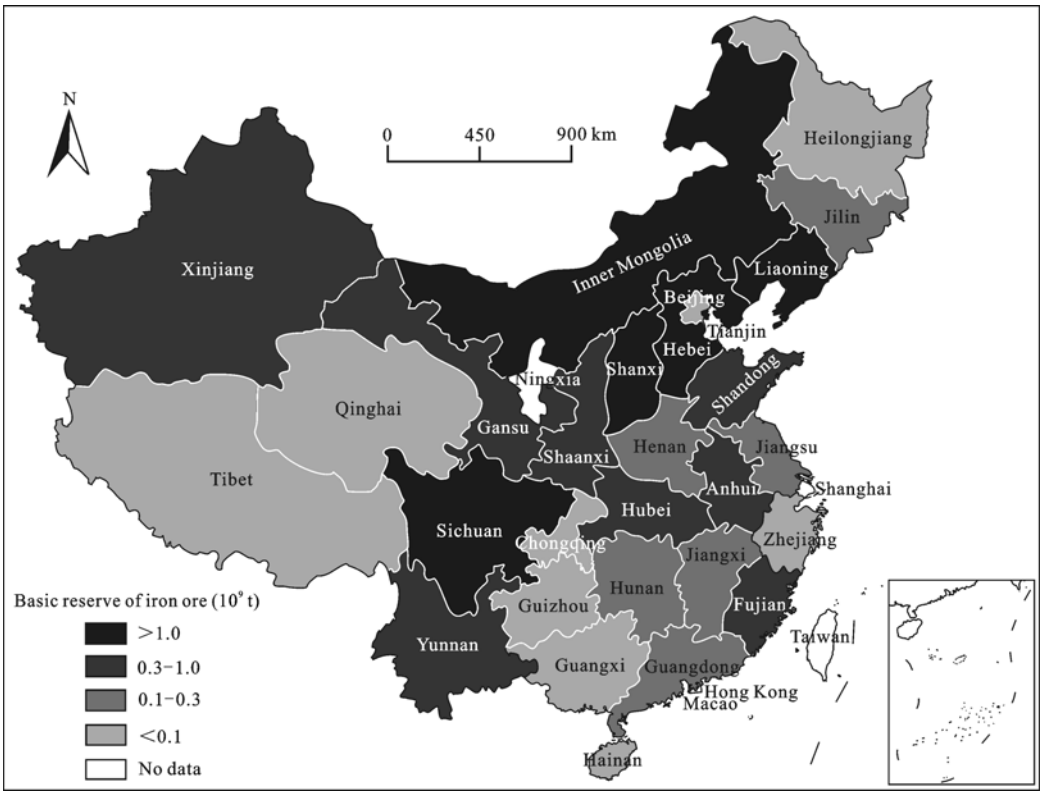

Fig. 3 Iron ore distribution in China in 2011 (NBSC, 2012a)

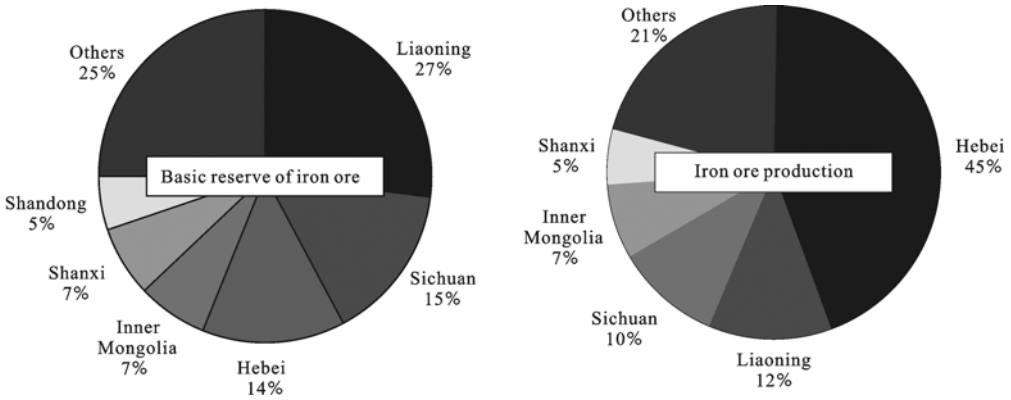

Fig. 4 Basic reserve and production distribution of iron ore in China in 2011 (NBSC, 2012a)

ince only produces 12% of the iron ore, but it has 27% of the basic reserve. These inconsistencies demonstrate that iron ore reserves have been over-exploited in Hebei, and Liaoning has low resource utilization efficiency, which constrains the sustainable use of iron ore in China.

2.3 Copper

China is relatively poor in copper mine. In 2011, China had a basic copper reserve of 2.812×10^7 t. The copper distribution in China is relatively concentrated, with the basic reserves of Jiangxi, Inner Mongolia, Yunnan, Tibet and Shanxi accounting for 63% of the total reserve (Fig. 5, Fig. 6). In 2011, China had a copper mine production of 1.27×10^6 t, with the output in Jiangxi, Yunnan, Inner Mongolia, Anhui and Xinjiang accounting for 69% of the total production (Fig. 6). These figures indicate that the distribution and production of copper are relatively concentrated in the central and western China, which has a harsh environment and is geographically distant from the high copper demands in the eastern China.

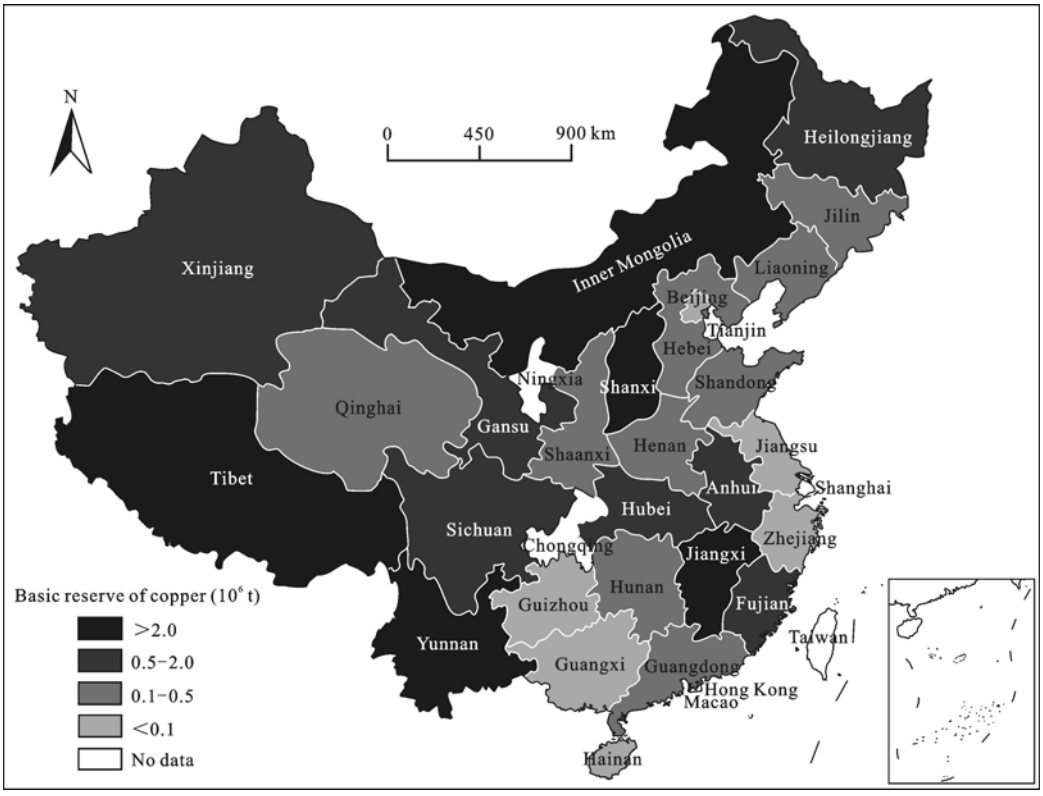

Fig. 5 Copper distribution in China in 2011 (NBSC, 2012a)

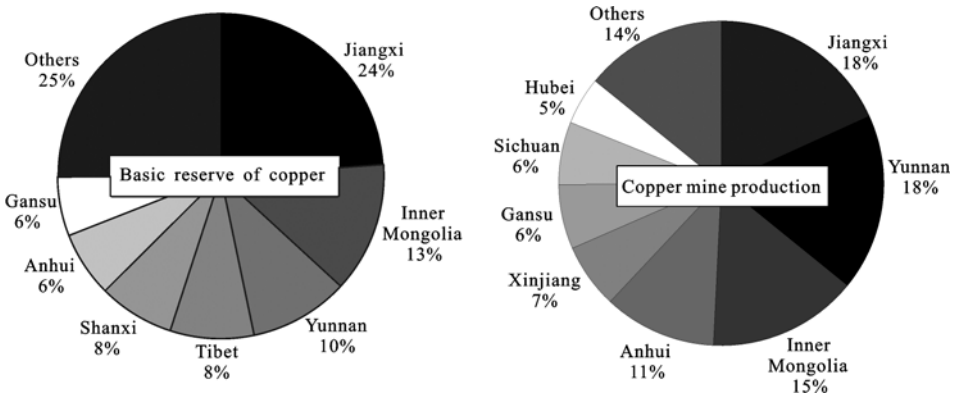

Fig. 6 Basic reserve and production distribution of copper in China in 2011 (NBSC, 2012a; China Non-ferrous Metals Industry Association, 2012)

2.4 Bauxite

In 2011, China had a basic bauxite reserve of 1.05×10^9 t, which was highly concentrated mainly in Guangxi (39%), Henan (19%), Guizhou (17%) and Shanxi (15%) (Fig. 7). The bauxite in these four provinces accounted for 90% of the national basic reserve in 2011 (Fig. 7). Meanwhile, the most above-mentioned provinces had the largest bauxite production. The bauxite resources are distributed in the central and western China and, similar to the copper, are not used sustainably.

3 Incompatibility of Mineral Resources Distribution and Regional Economic Development

In China, the mineral resources are mainly distributed in the central and western regions, but the economic and resource consumption centers are in the eastern region, which results in the misalignment of mineral resources distribution and regional economic layout and the separation of production and consumption. The eastern China

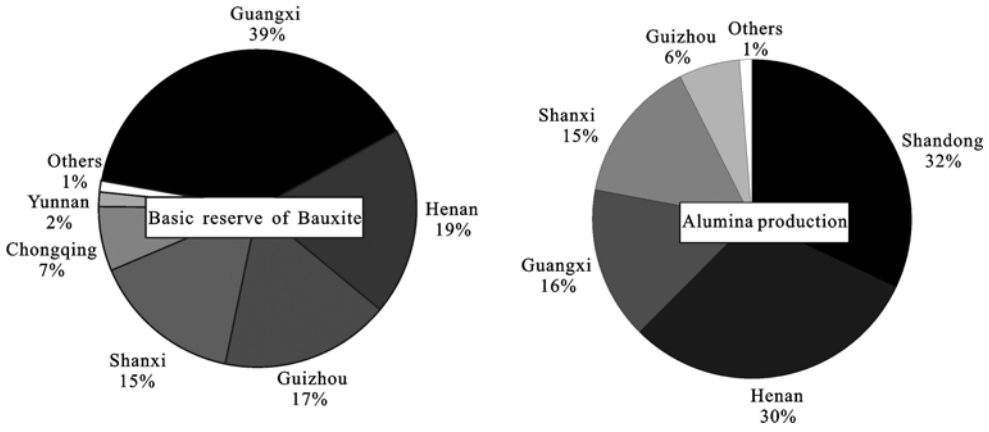

Fig. 7 Basic reserve and production distribution of bauxite in China in 2011 (NBSC, 2012a; China Non-ferrous Metals Industry Association, 2012)

is densely populated, economically strong and has a large demand for natural resources, but the region contains far fewer mineral resources than the central and western China. In 2011, the population and GDP of the eastern China were, respectively 45% and 57% of China′s total, while its mineral industry only produced 31% of China′s total production (Table 1, Fig. 8 and Fig. 9). In 2011, the coal consumption in China was 3.52×10^9 t, of which the eastern China consumed 1.55×10^9 t, or 44% of China′s total (Table 1, Fig. 10). In contrast, the basic reserve and output of coal in the eastern China were only 11% and 14%, respectively (Table 1). Although the eastern China has quite a few iron ore reserve, the proportion of the iron ore amount in production and consumption is surprisingly more than 65% of the whole country′s total (Table 1, Fig. 11). In the same year, the output and consumption of copper in the eastern China were 35% and 34%, respectively, while the basic reserve in the eastern China was only 13% (Table 1, Fig. 12). The inconsistency between production and consumption is also present for bauxite, natural gas and potassium in the eastern, central and western China.

Table 1 Proportion of economics and mineral resources of eastern, central and western China (%)

	Eastern	Central	Western
Population	45	32	23
GDP	57	24	19
Mineral industry production value	31	34	35
Coal basic reserve	11	38	51
Coal production	14	34	52
Coal consumption	44	29	27
Iron basic reserve	63	11	26
Iron production	66	10	24
Iron consumption	67	21	12
Copper basic reserve	13	43	44
Copper production	35	21	44
Copper consumption	34	21	44

Sources: NBSC, 2012a; 2012b; China Non-ferrous Metals Industry Association, 2012

4 Problems in Mineral Resources Exploitation

4.1 Transportation problem

The supply source of minerals in China is not in geographic proximity to their demand destination, which causes the need for transportation and increases the costs of development and exploitation, thus hindering the sustainable exploitation and development of mineral resources. Over time, the regional distribution of mineral resources became increasingly misaligned with its supply and demand layout. Coal, natural gas and electricity transportation across various regions of China have already caused complications for the country in developing and using its natural resources. In 2010, 2.2×10^9 t of coal was transported by land, and the transportation volume/production ratio was as high as 80%. The volume of coal transported just from Shanxi, Shaanxi and Inner Mongolia has reached 1×10^9 t. The need to move such large volumes has brought China's transportation system under great pressure. To compound the problem, the Natural Gas Transmission Project that runs from the western to the eastern China (Phase 3) crosses 10 provinces with a total length of 7378 km. Such an extensive project requires a capital of

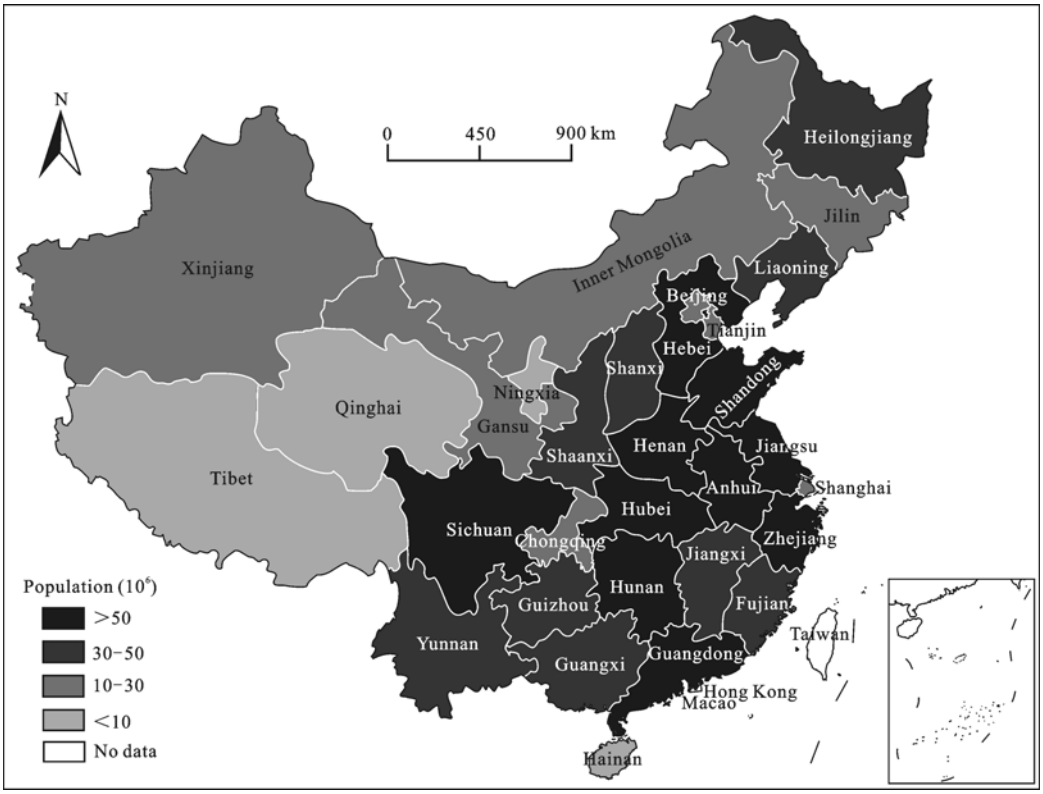

Fig. 8 Population distribution in China in 2011 (NBSC, 2012a)

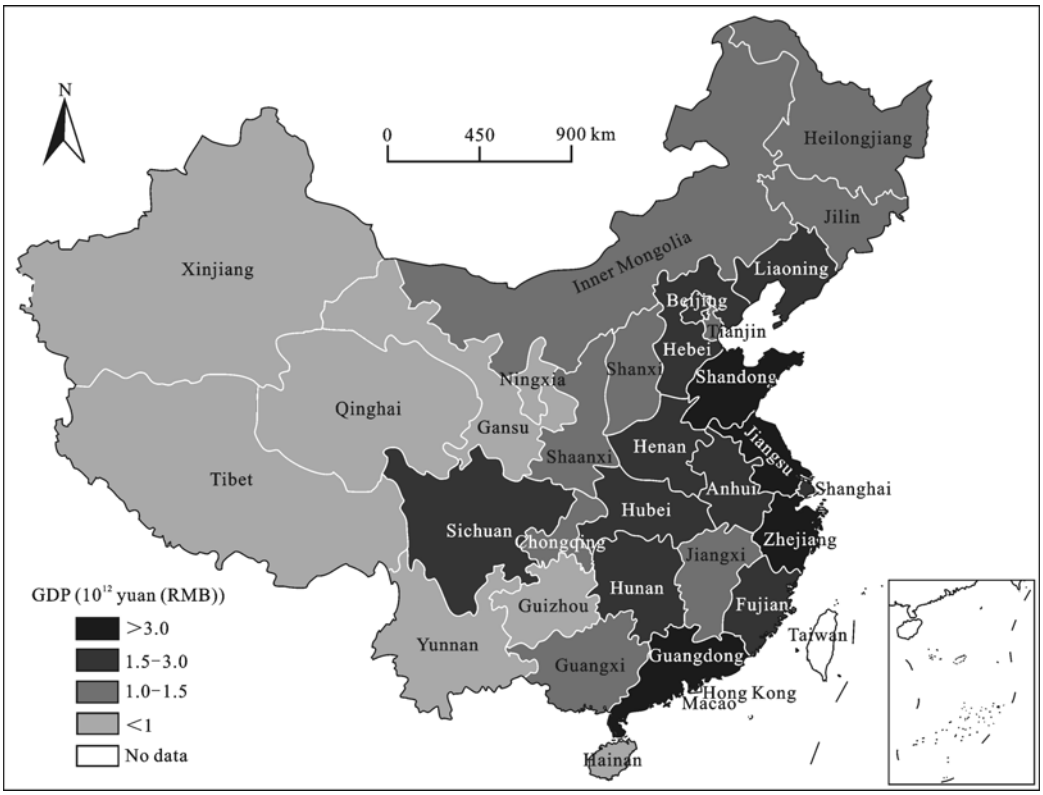

Fig. 9 GDP distribution in China in 2011 (NBSC, 2012a)

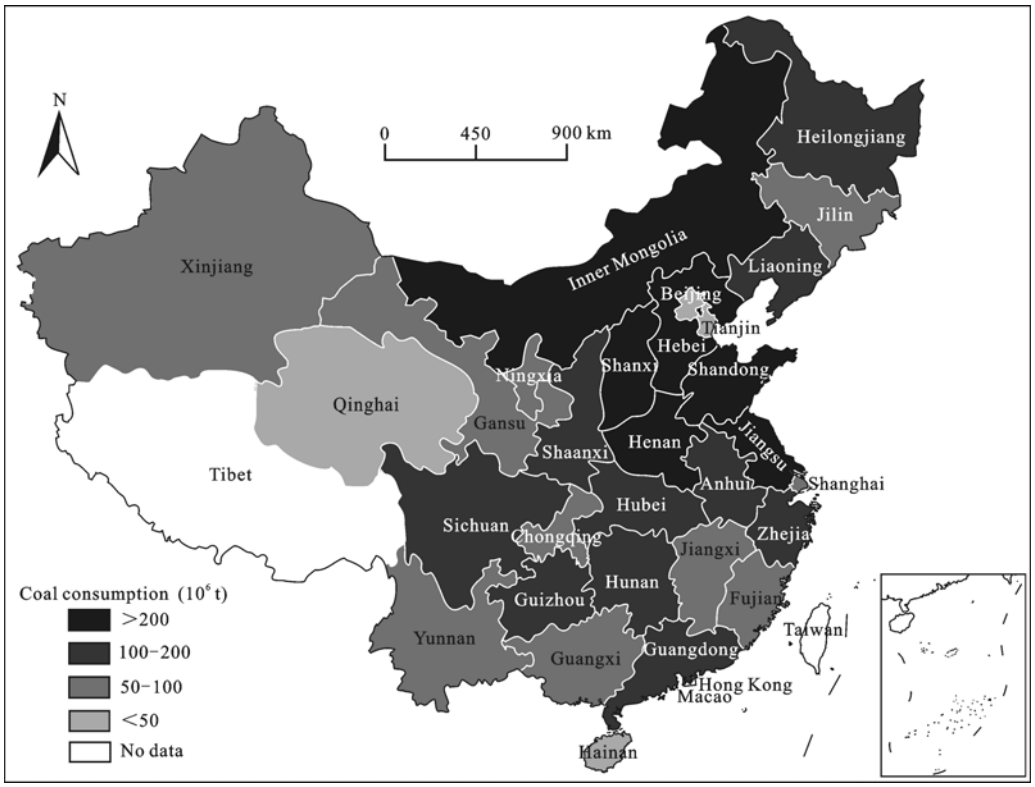

Fig. 10 Coal consumption distribution in China in 2011 (NBSC, 2012b)

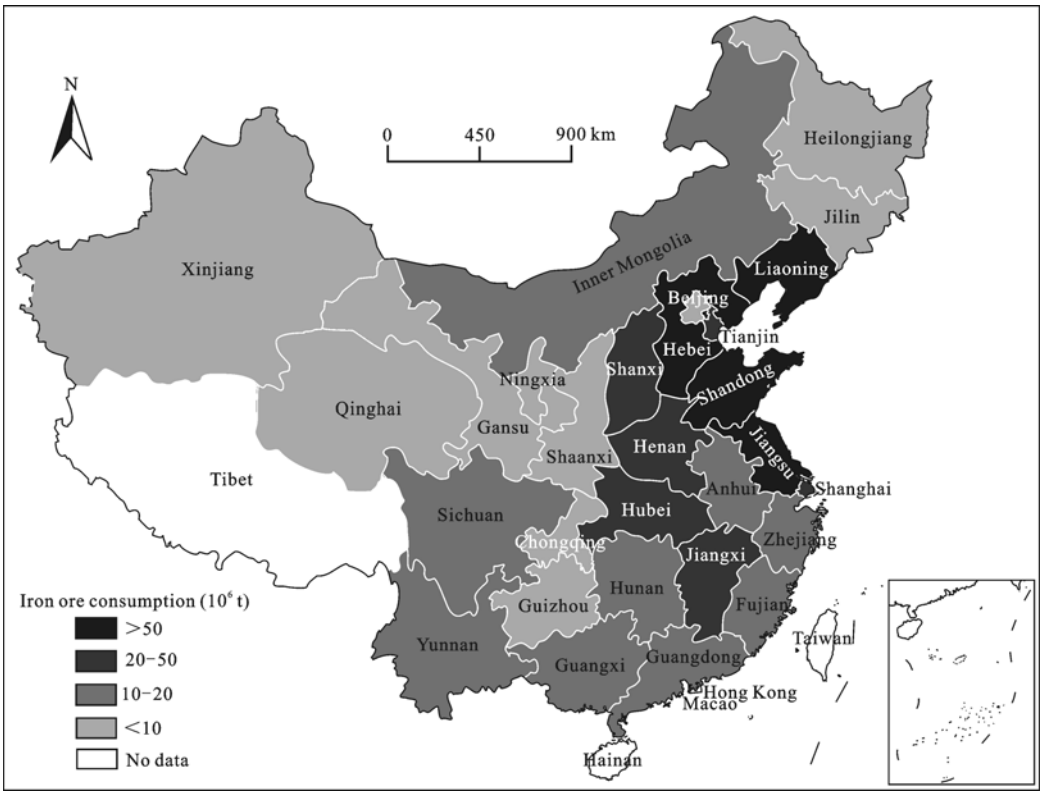

Fig. 11 Iron ore consumption distribution in China in 2011 (NBSC, 2012a)

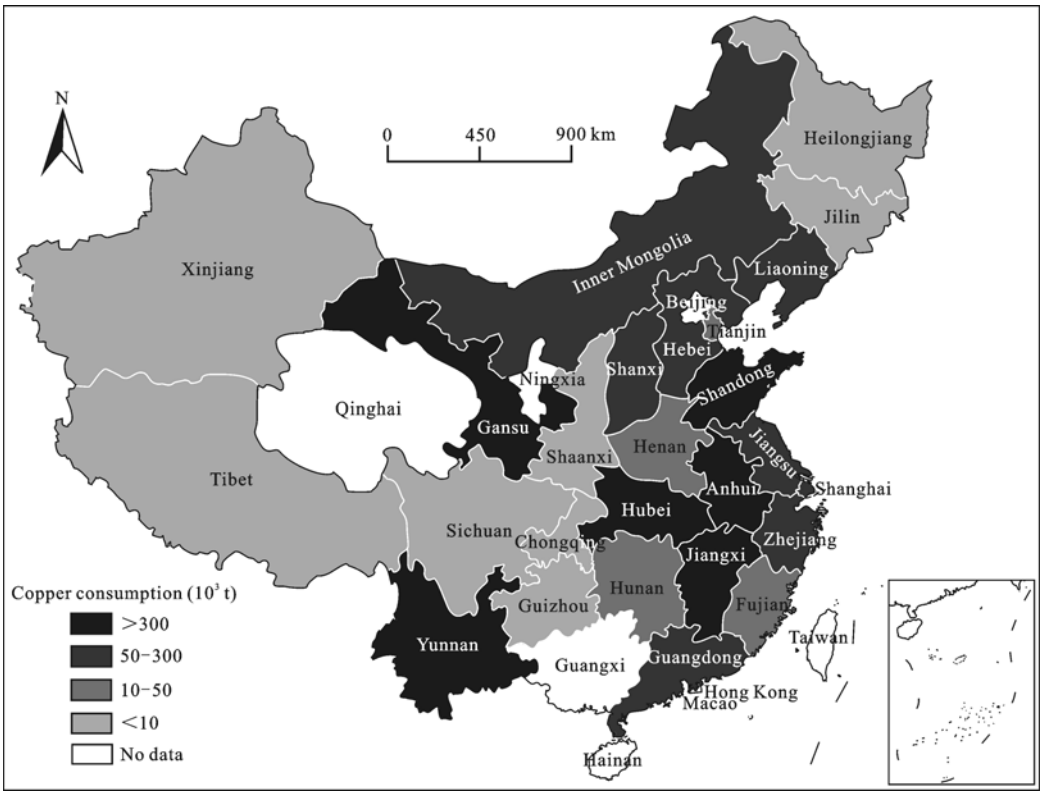

Fig. 12 Copper consumption distribution in China in 2011 (NBSC, 2012a)

1.25×10^{11} yuan, which significantly increases the development costs of the mineral resources. The threat of natural disasters is also a concern for the long-distance transportation systems. Catastrophic disasters have the potential to cause coal shortages and loss of power in the eastern China, which can endanger national security and people′s lives.

4.2 Overexploitation problem

4.2.1 Overexploitation of mineral resources in China

In the last decade, the rapid increase in consumption of Chinas mineral resources led to predatory exploitation. In 2011, China, with only 13% of the world′s reserve, produced nearly 50% of the coal in the world; with only 13% of the world′s iron ore reserve, produced 43% of the world′s raw iron ore; with 4% of the world′s copper reserve, produced nearly 8% of the world′s copper; and with 3% of bauxite reserve, generated 18% of the world′s bauxite. The predatory exploitation of mineral resources caused the sustainable life statistics of most mineral resources (ratio of basic reserve to production) in China to lag far behind the global average (Fig. 13), much lower than the countries with rich mineral resources, such as America and Australia. Globally, the sustainable life statistics for coal, iron ore and bauxite are 118, 61 and 132. In China, however, the sustainable life statistics for such minerals are only 35, 19 and 18, respectively, which are far below the world average; these data are indicative of the outstanding issues of sustainable exploitation of mineral resources in China.

4.2.2 Overexploitation of mineral resources in eastern China

The eastern China is scare in mineral resources. The rapid economic development demands a large quantity of mineral resources, which causes the production of mineral resources to increase sharply. In the provinces of the eastern China that are rich in mineral resources, such as Hebei, Liaoning and Jiangxi, the sustainable life statistics of their important mineral resources are very low. When comparing the sustainable life statistics in each province in 2011, it can be observed that due to overexploitation, the sustainable life statistics of coal, iron ore and copper in the eastern China are far below those in the central and western China. In the eastern China, the sustainable life statistics of coal, iron ore and copper are 60.5, 11.9 and 6.8, respectively, being lower than those 91.7, 20.0 and 37.3 in the central China (Table 2). Although the central and western China has large

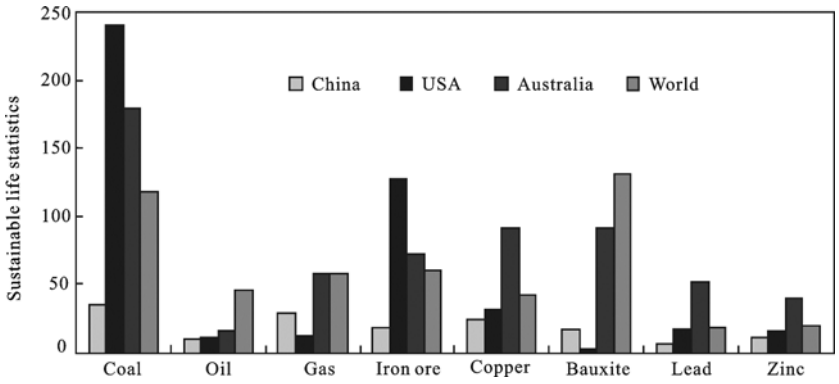

Fig. 13 Sustainable life statistics of mineral resources in China, USA and Australia and world average in 2011 (ratio of reserve to production) (BP, 2012; USGS, 2012)

resource outputs, they are relatively rich in mineral resources, so their sustainable life statistics are relatively longer than those of the eastern China. The overexploitation of mineral resources in the eastern China greatly reduced the sustainability, which exhausted the resources of several mining cities. Because these cities did not have alternative industries to produce revenue, serious social problems arose.

Table 2 Sustainable life statistics of coal, iron ore and copper in different regions of China

Region	Coal	Iron	Copper
Eastern	60.5	11.9	6.8
Central	91.7	20.0	37.3
Western	81.3	19.8	18.9
National average	61.3	14.5	23.9

Sources: NBSC, 2012a; China Non-ferrous Metals Industry Association, 2012

4.3 Environmental pollution problem

The western China is rich in mineral resources. Compared to China′s total basic reserve, the western China accounts for 51% of the coal reserve, 26% of the total iron ore reserve and 44% of the total copper reserve, and has production ratios of 52%, 24% and 44%, respectively. It is evident that the western China is the country′s supply base for mineral resources, especially since the recent implementation of the West Development Strategy, which caused the production of mineral resources to rapidly increase. From 2000 to 2011, the production of coal, iron ore and copper in the western China has increased by 3, 8 and 5 times, respectively (NBSC, 2001; 2012a).

The western China is a vast area with a small population, low vegetation coverage and vulnerable ecological environment. The large-scale exploitation of mineral resources has seriously contaminated the vegetation, soil and underground water. From 2000 to 2011, the amounts of solid waste, wastewater and gas emitted by the mineral production processes in the western China have increased by 1.7, 5.4 and 2.4 times, respectively (NBSC, 2001; 2012a). In 2011, the solid waste, wastewater and gas emission by the mineral resources production in the western China were 3.5×10^8 t, 8.3×10^8 t and 7.0×10^8 t, accounting for 39%, 47% and 43% of China′s total emissions, respectively (NBSC, 2012a). Such significant amounts of pollutant emission endanger the fragile ecological environment in the western China, thus emphasizing the challenges of sustainable development of mineral resources in the region.

In general, from the perspective of the geographic layout of the mineral resources industry, harmonious development is needed to maximize the economic and environmental benefits. Specifically, the mineral resource industry needs to build a supply base, which would not only enhance the efficiency of resources and maximize the economic benefits but also resolve the environmental issues to some extent. This suggestion is of great practical significance to China′s West Development Strategy.

5 Proposals Regarding Sustainable Development of Mineral Resources

(1) Accelerate the transformation of economic development and effectively control the demand for mineral resources. The development model of China as the ′World Factory′ causes an unsustainable amount of resources consumption and environmental pollution. It is

therefore necessary to accelerate the adjustment of the industry structure, strictly control the capacity of industries with high energy and materials consumption, limit the exportation of preliminary mineral products, improve the ratio of the service industry in the national economy and effectively control energy needs. In the meantime, to save resources and improve energy utilization efficiency should be promoted to achieve green economic and societal development.

(2) Implement 'Prospecting Breakthrough Strategy' to improve integrated utilization rate, secondary utilization level and sustainability of mineral resources. It is necessary to implement the 'Prospecting Breakthrough Strategy' by emphasizing the importance of geological work, expanding the staff of the mineral companies, improving funds and materials to identified resource reserves and building a series of mineral prospecting backup centers that effectively enhance the sustainability of mineral resources in China. It is also necessary to make the most of the integrated resources utilization, improve the integrated utilization level of mineral resources and mitigate the demand from the resource extraction processes. It is necessary to attach more importance to secondary utilization of resources, prepare a scientific-based secondary utilization mechanism for mineral resources and improve the secondary utilization rate.

(3) Scientifically plan prospecting and development of mineral resources and regional economy development layout. It is necessary to assess the mineral resources distribution and regional economy development layout comprehensively and plan the prospecting and development structure scientifically. It is imperative to examine the major economic regions, effectively increase resources reserves and enhance the sustainability of mineral resources. Furthermore, it is important to scientifically plan the development of mineral resources in the eastern China, to reduce the current overexploitation and to achieve sustainable development of mineral resources for the regional economy.

(4) Proactively encourage the mineral industries to optimize, upgrade and transfer. After long-term exploitation in the eastern China, many mines are nearly exhausted and the resource-based cities face the predicament of transforming their industry. It is important to promote the transformation of mineral-based cities by encouraging them to seek new modes of economic growth, such as generating tourism, building a geological park and creating sustainable development of both mineral and non-mineral industries. At the same time, the regional economic development strategy should include the orderly transfer of the mineral industry from the eastern China to the western China.

(5) Make every effort to recover environment affected by mining and raise environmental standards for mineral industries in the central and western China. With policy and capital support from the government, the polluting industries can be held accountable for the environmental recovery and the offending enterprises can be closed. However, with the transition of the mineral industry from the eastern China to the central and the western China, the western China faces much tougher environment issues. Precautions should be taken as early as possible to increase environmental standards. Prevention, followed by remediation, should be the top priority, which would create a 'Green Mineral Industry' in China and achieve the sustainable development of mineral resources.

6 Conclusions

In summary, we can draw some conclusions as follows:

(1) The spatial distribution of mineral resources in China has the fundamental feature of unbalance and the separation of production and consumption. The eastern China is the main resource consumption region, but the important resource distribution and production regions are more concentrated in the central and western China, which result in the mismatching between mineral resources distribution and regional economy layout.

(2) The main problems in the development and utilization of mineral resources are involved in transportation, overexploitation and environmental pollution. The separation of production and consumption has greatly increased the transportation cost of utilizing of mineral resources. China, especially the eastern region, is facing the serious problem of overexploitation of mineral resources. And environmental pollution, especially the aggravatingly environmental pollution in the fragile western region, restricts the sustainable development and utilization of mineral resources in China.

(3) The effective measures to guarantee the sustainable utilization of mineral resources are as follows: Accelerate transformation of the mode of economic devel-

opment; control the demand for mineral resources; raise the utilization efficiency of mineral resources; plan prospecting and development of mineral resources and regional economy development layout; encourage the mineral industries to optimize, upgrade and transfer; and raise environmental standards for mineral industries.

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