IOP Conf. Series: Materials Science and Engineering **397** (2018) 012107 doi:10.1088/1757-899X/397/1/012107

Contribution analysis of recycled aluminum supply in China based on sustainable supply

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Abstract. Nowadays, it's an urgent task for all mankind to maintain sustainable development in all aspects. In terms of resources, it's necessary for every country to ensure its sustainable and secure supply to meet the needs of productivity and living. This paper applied Herfindahl Hirschman Index (HHI) to quantify the supply risk of China's aluminum resource, and quantitatively measures the contribution degrees of recycled aluminum on the basis of forecast of primary aluminum demand and recycled aluminum supply. The main results show that there exists increasingly serious supply risk, and the primary aluminum demands of China are respectively 3500, 3600 and 3300 ten thousand tons, the amounts of recycled aluminum supply are 1000, 1200 and 1100 ten thousand tons in 2020, 2025 and 2030. The contribution degree of recycled aluminum supply on total aluminum consumption demand is predicted to be around 25% in the near future. The another contribution degree of recycled aluminum supply on total guarantee degree is more than 10% at the comparison foundation of the year 2016, and it is expected to increase to above 20%. Besides, the cyclic utilization of aluminum scrap will obtain better economic and environmental benefits. Therefore, the cyclic utilization of waste resource is an inevitable tendency.

1. Introduction

Mineral resources are the main and basic sources of human living and production materialist, and are the material basis for the development of social civilization. Mineral resources account for 70% of the whole natural resources utilized by mankind. In China, for example, it directly provides more than 80% of industrial raw materials, about 90% of energy, 70% of agricultural production materials and over 30% of water for life [1, 2]. Mineral resources can be mined and exploited, but it can't be artificially created and it is obviously non-renewable and unsustainable. Compared with the infinite and ever-increasing demand of mankind, mineral resources are always limited and even scarce in certain time and space. Aluminum is the second most abundant metallic element in the earth's crust after silicon, accounting for 8% of the earth's crust [3], but is a comparatively new industrial metal that has been produced in commercial quantities for just over 100 years [4]. However, more aluminum is produced today than all other nonferrous metals combined [5]. Due to its excellent characteristics, the great demand and enormous consumption of aluminum-containing products emerges in recent decades [4, 6-7].

Although China is still an undeveloped country, it is also a populous and fast-developing country and it has a potential to influence the entire world's use of materials [8]. China has been the world's largest producer and consumer of aluminum [9], and the average growth rate of China's aluminum production and consumption is about 4 times the global level in the period of 1991-2007 , especially after 2000 [10]. On the contrary, the bauxite ore reserves in China are only around 3% of the world's, and per capita reserves are only one-tenth of the global average. So, China's bauxite ore resources are very poor and dependent on importing. The net import dependence indexes of China's bauxite and aluminum scrap used to product respectively primary and secondary aluminum were thus constantly increasing, and around 50% at present [11]. In other words, half of the raw materials to product aluminum ingots need to import from other countries, and its sustainable and secure supply will face a great challenge. In previous research, the total supply guarantee degrees have been gradually decreasing since 1996; steady around 50% [12]. Its supply risk really exists and resource constraints will persist for a long time.

Studies have shown that the energy required and pollution discharged for producing secondary aluminum might be only 5-10% of that needed for primary aluminum [13], and cyclic utilization of this non-renewable resource will reduce resource consumption to a large extent. Aluminum is the best recyclable metal in industrial active metal materials. The quality of recycled aluminum is hardly lower than primary aluminum, and it's a veritable "green metal material" [14]. Typical developed countries in the world pay great attention to the recycling of aluminum. The proportions of recycled aluminum on total aluminum output have been augmenting, which of quite a few industrialized countries have reached or exceeded 50%. However, the supply structure of China's aluminum metal in recent years is about: 80% for primary aluminum, 20% for recycled aluminum [12]. Huge amounts of production and consumption of China's aluminum metal provide favorable conditions to its cyclic utilization after the Reform and Opening, in particular 21st century. Then, China is supposed to seize this superiority to promote relevant laws, regulations and policies, and improve the waste recovery system, hoping to solve the unsustainable problem of aluminum resource constraints and supply risk.

There are so many studies about measurement and prediction of recycled aluminum output and potential, but how many the contribution degrees of recycled aluminum to its total guarantee degrees. Very few scholars focus on this topic and measure this value.

2. Methods

2.1. Herfindahl Hirschman Index (HHI)

HHI is a comprehensive index that measures the concentration degree of a industry. It is proved to be a good indicator among many other indicators, and often used by the economic circle and the government control department. So it can be applied to measure the concentration degree of China's bauxite output, primary aluminum production, and consumption amount on world's respectively [70]. The gap between the former and the latter will show the extent of the supply risk of China's aluminum industry. HHI is calculated by the following formula:

$$HHI = \sum_{i=1}^{N} (X_i / X)^2 = \sum_{i=1}^{N} S_i^2 \quad (1)$$

Where HHI depicts a measure to analyze the market concentration, X is the total size of world market (the global gross), X_i shows the amount of country i, S_i expresses the market share of country i, N denotes the number of country that will be calculated. This paper only calculates the market concentration of a country, so the formula becomes the following form:

$$HHI = \left(X_t / X\right)^2 = S_t^2 \quad (2)$$

and $t = 1,2,3$ represents the bauxite output, primary aluminum production, and consumption amount in China respectively. The higher the HHI value, the higher the market concentration degree, and the lower the supply risk. In the same time, the higher the gaps between primary aluminum production HHI and bauxite output HHI, between consumption amount HHI and bauxite output HHI, the higher the supply risk, and the lower the sustainable and secure supply.

2.2. Primary and Recycled Aluminum Supply Forecast

Before measuring the contribution degree of recycled aluminum in China, the amounts of primary aluminum and recycled aluminum must be predicted. As we all know, any prediction has deviation and inaccuracy at a certain extent, so multiple methods are used in this paper to estimate to minimize the deviation and inaccuracy.

Primary aluminum prediction adopts the “S” shape model method and department consumption method. The “S” shape model method, a popular method, was created by the global center for mineral resources strategic research of Chinese Academy of Geological Sciences, and it is based on the overall “S”shape trend of primary aluminum consumption per capita and GDP per capita. It conducts cross-section analysis for primary aluminum consumption peak year of typical developed countries in its industrialized process, and it sets low, reference and high scenarios according to China’s economic development goals to analyze China’s primary aluminum consumption demand in the future. The department consumption method is to divide primary aluminum consumption into different departments, and can get the final demand amount of primary aluminum through summing the consumption amount of each department.

In the same way, recycled aluminum supply prediction adopts sector supply method, regression analysis method, and ratio analysis method. New scrap, old scrap, and aluminum slag generated during electrolysis and remelting are the three main parts of recycled aluminum, and they can be viewed as three sectors. The sector supply method is to calculate the total amount of aluminum scrap in three sectors. Regression analysis method takes the advantage of the positive correlation between recycled aluminum supply and primary aluminum consumption. Obviously, ratio analysis method mainly uses the proportion of recycled aluminum generation on primary aluminum production and consumption to estimate and forecast the future amount of recycled aluminum generation and supply.

2.3. Contribution Degrees of Recycled Aluminum

The contribution degree CD_1 of recycled aluminum supply on total aluminum consumption demand is calculated by the following formula:

$$CD_1 = RA/(RA + PA) \tag{3}$$

RA and PA denote respectively the amount of recycled aluminum supply prediction and primary aluminum demand prediction. The contribution degree CD_2 of recycled aluminum supply on the total guarantee degree [12] is calculated through formula (4):

$$CD_2 = TSG_1 - TSG_2 \tag{4}$$

TSG_1 expresses the total supply guarantee degree after making full use of waste aluminum, that is cyclic utilization, and TSG_2 expresses the total supply guarantee degree without full use of aluminum scrap, that is previous level. In the meantime, CD_2 also denotes the growth ratio of China’s aluminum resource guarantee degree. This will add a safeguard to sustainable and secure supply of aluminum resource.

3. Results and Discussions

3.1. Domestic Aluminum Supply Risk

The concentration degrees of the domestic bauxite output, primary aluminum production, and consumption amount on that of the globe both gradually increased little by little, particularly HHI_2 and HHI_3. The concentration degrees of those augmented to 0.06, 0.29 and 0.30 in 2016. The gaps between HHI_2 and HHI_1, HHI_3 and HHI_1 are widening inch by inch. This signifies that there is relatively less bauxite output, nevertheless more primary aluminum production and consumption, which account for more than 50% of the globe. The supply risk of aluminum resource in China will be obvious due to such a huge gap. Besides, the aluminum consumption demand still rises along with the rapid economic development (Table 1), but domestic bauxite is less and less. The aluminum resource supply situation is seriously severe.

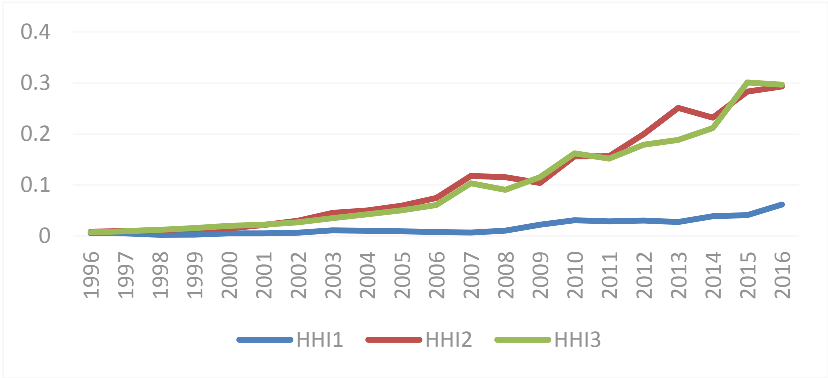

Figure 1. The change trend of domestic aluminum supply risk in 1996-2016.

3.2. Aluminum Resource Supply Forecast

From the combination of "squeeze S" shape model method and department consumption method, the peak point of primary aluminum consumption will reach at around 2023, when the primary aluminum consumption demand is 3700 ten thousand tons. The primary aluminum demands of China are respectively 3500, 3600 and 3300 ten thousand tons in 2020, 2025 and 2030. The primary aluminum consumption trajectory of China has the characteristics of forward, and it conforms to the facts that the primary aluminum of large scale was applied to early industrialization process in China (the U.S., Japan and other developed countries began to use aluminum of large-scale in middle or late industrialization course), and the industrialization development pattern of compression occurred in China.

Table 1. The forecast result summary of primary aluminum demand. unit: ten thousand tons

Forecast Method	Time	2020	2023	2025	2030
	High Scenario	3900	3743	3641	3400
"S"Model	Reference	3500	3700	3581	3300
	Low Scenario	3294	3416	3500	3200
Department Consumption		3482	—	3551	3289
Summary		3500	3700	3600	3300

The comprehensive prediction results of recycled aluminum supply obtained from above three methods. The amounts of it in 2020, 2025 and 2025 in China are 1000, 1200 and 1100 ten thousand tons, and the ratios of it on primary aluminum consumption demand are 29%, 33% and 33%. The year 2023 is the peak point of aluminum consumption, and the recycled aluminum amount is 1300 ten thousand tons, the ratio is 35%.

Table 2. The forecast result summary of recycled aluminum supply. unit: ten thousand tons

Forecast Method	2020	2023	2025	2030
Sector Supply	430	564	710	1465
Regression Analysis	834	880	857	788
Ratio Analysis	1050	1295	1260	1155
Result Summary	1000	1300	1200	1100
Ratio *	29	35	33	33

* ratio of recycled aluminum supply on primary aluminum consumption

3.3. Contribution Degrees

It can reduce the huge pressure of aluminum resource supply, energy conservation and emission reduction if China improves the waste recovery system and makes full use of waste aluminum. The total aluminum demand is the addition between primary aluminum consumption demand and recycled aluminum supply. The contribution degree CD_1 of recycled aluminum supply on total aluminum consumption demand is predicted to be around 25% in the near future (Table 3).

Table 3. The contribution degree of recycled aluminum supply on total aluminum demand

Time	Total Aluminum Demand *	Recycled Aluminum Supply *	CD_1
2020	4500	1000	22
2025	4800	1200	25
2030	4400	1100	25

* unit: ten thousand tons

If the import proportion of bauxite in China keeps on around 50%, then the guarantee degree of primary aluminum P_p^s [1]is at around 50%. There is an assumption that the aluminum scrap used to remelt recycled aluminum is all self-productive, so the CD_1 is equal to the guarantee degree of recycled aluminum P_s^s [2]. Besides, this paper assumes that the import and export of aluminum is still basically flat, which has little impact on the calculation of guarantee degree and contribution degree. At the moment, the total supply guarantee degree TSG_1 can reach more than 70%, from a shortage state to a guaranteed state.

Table 4. The contribution degree of recycled aluminum supply on total guarantee degree

Time	P_p^s (%)	P_s^s (%)	TSG_1 (%)	CD_2 (%)
2020	50	22	72	10
2025	50	25	75	13
2030	50	25	75	13

After forecast and measurement, the full cyclic utilization of aluminum scrap obviously makes the total supply guarantee degree increase much during the period of 2018-2030. This study takes the year 2016 as the comparison foundation, and it increases more than 10%, that is CD_2 .

Under the background of sustainable development and ecological civilization construction, the values of CD_1 and CD_2 will increase little by little. On the one hand, China's international status will gradually improve, and the situation of overseas investment and exploitation and utilization will also take a turn for the better, therefore it can be a effective resource support for China. Then the import proportion of bauxite will decline, and at this moment P_p^s [12] will increase more than 50%. On the other hand, because the aluminum scrap recycling system will be established and improved step and step, and the treatment technologies of aluminum scrap will continue to progress in each sub-stage to break through the limitations and bottlenecks of the present, then recycled aluminum supply is expected to be more than the prediction, and now P_s^s ([12], mean CD_1) will increase more than 25%.

To sum up, the total supply guarantee degree TSG_2 of China's primary and recycled aluminum resource will enhance to above 80%, and the increasing proportion (mean CD_2) will reach to 20%, largely due to the contribution of sufficient cyclic utilization of aluminum scrap. That is to say, the recycled aluminum supply contributes greatly to the improvement of aluminum resource guarantee degree. So you can see that, strengthening the recycling and sufficient cyclic utilization of aluminum scrap resource has profound significance to realize its sustainable supply, reduce the import costs and trade uncertainty, and it has obvious effects for energy conservation and emission reduction.

4. Conclusion

Facts have proved that the bauxite reserves of China is so few comparison with the globe, nevertheless its production and consumption demand are both enormous, accounting for more than 50% of the world. Thus the supply risk of aluminum resource in China is realistic, and upstream resource constraints are severe.

After forecasting, the primary aluminum demands of China are respectively 3500, 3600 and 3300 ten thousand tons, and the amounts of recycled aluminum supply are 1000, 1200 and 1100 ten thousand tons in 2020, 2025 and 2030, and the ratios of it on primary aluminum consumption demand are 29%, 33% and 33%. The contribution degree of recycled aluminum supply on total aluminum consumption demand is predicted to be around 25% in the near future. The another contribution degree of recycled aluminum supply on total guarantee degree is more than 10% at the comparison foundation of the year 2016, and it is expected to increase to above 20%. Besides, cyclic utilization of aluminum scrap will relieve the pressure of energy saving and emission reduction, and save economic costs such as importing bauxite and aluminum scrap, environmental governance, resource exploitation and so on, and it plays an important role to promote the implementation of sustainable development strategy.

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