DOI 10.15302/J-SSCAE-2019.01.018

# Development Strategy for Phosphate Rock Resources in China Under Global Allocation of Resources

**Cui Rongguo[1], Zhang Yanfei[2], Guo Juan[1], Guo Zhenhua[1], Xiao Yuping[1]**

1. Information Center of Ministry of Natural Resources of the PRC, Beijing 100812, China
2. Institute of Mineral Resources, Chinese Academy of Geological Sciences, Beijing 100037, China

**Abstract:** In this paper, the sigmoid growth curve model is adopted to predict the future demand for phosphate rock resources in China for both high- and low-demand scenarios. Data indicate that the total demand for phosphate rocks in China, which will reach approximately 2.2−2.7 billion tons between 2017 and 2050, can be met by domestic supply. Additionally, the relationship between the status quo and the demand for phosphate rock is analyzed with a view to its current production status. Analysis shows that China's production of phosphorus rock significantly exceeds its needs. With 4.7% of the world's phosphorus reserves, China is currently supplying phosphorus rock to more than 50% of the global market. If this development intensity continues unabated, China will begin to experience a shortage of phosphate rocks by 2050. To guarantee a sustainable supply of this resource in future and thereby ensure food security, it is recommended that China exercise strict control over domestic production capacity, limit production, and utilize global resource allocation to facilitate the development of foreign resources.
**Keywords:** phosphate rock; non-renewable; phosphate fertilizer; cumulative demand; resource shortage

## 1 Introduction

Phosphate is a type of non-renewable non-metal mineral resource found naturally within the Earth. Phosphorus is an important element for cytoplasm, and it is also essential for plant growth. Therefore, phosphate is important for the existence of life on Earth, making it an indispensable mineral resource for food security. In fact, it could be said that the development of human civilization is inseparable from availability of phosphate resources [1].

The aim of this paper is two-fold. Firstly, an analysis of both the global phosphate consumption structure, and that of China, is conducted. Secondly, China's future phosphate demands are forecast using the sigmoid growth curve. The relationship between the current state of Chinese phosphate rock reserves and China's predicted phosphorus demands is then analyzed. Finally, the paper proposes a strategy for the sustainable development of China's phosphate resources. Significantly, the phosphate rock demand predicted in this paper pertains to China's effective domestic demand only, and does not include export-related phosphorus demands (e.g. phosphate fertilizers).

## 2 Phosphate consumption structures

Since the discovery of phosphorus in 1669, the mineral has found widespread application in the defense, aviation, aerospace, chemical, and food industries, with the phosphate fertilizer industry being the primary consumer [2].

Globally, 66% of all phosphate rock is used for the production of solid diammonium phosphate (DAP), monoammonium phosphate (MAP), and triple superphosphate (TSP). The animal feed and food industries account

**Received date:** January 5, 2019; **Revised date:** January 25, 2019
**Corresponding author:** Zhang Yanfei, Institute of Mineral Resources, Chinese Academy of Geological Sciences, Associate Researcher. Major research fields are resource economics and mineral resources strategy. E-mail: zhyf1014@163.com
**Funding program:** CAE Advisory Project "Research on International Cooperation in Metallurgical Industries along the Belt and Road" (2017-ZD-15-05-01);
**Chinese version:** Strategic Study of CAE 2019, 21 (1): 128–132
**Cited item:** Cui Rongguo et al. Development Strategy for Phosphate Rock Resources in China Under Global Allocation of Resources. *Strategic Study of CAE*, https://doi.org/10.15302/J-SSCAE-2019.01.018

for 6% and 9% of global consumption, respectively, and the remaining 19% of the phosphorus consumed is utilized in other industrial products like detergents and metal phosphate coatings [3]. In China, phosphorus rocks are mainly used to produce phosphate fertilizers, which play an important role in increasing crop yields. According to 2017 industrial consumption estimates, the production of phosphate fertilizers, yellow phosphorus, and animal feed accounted for 75.6%, 11.1%, and 12.2% of phosphorus rock consumption in China, respectively. The remainder was attributed to phosphorus rock exports (0.6%) and other uses (0.5%). In comparison with global phosphorus consumption, China uses almost 10% more phosphate for phosphate fertilizers and 6.2% more for animal feed production. Industrial production accounts for a relatively small proportion of China's total phosphate consumption.

## 3 Prediction of phosphate demands

### 3.1 The current status quo

3.1.1 Global distribution of phosphate resources

Although phosphate resources are widely distributed throughout the world, this distribution is not uniform. The world's phosphate resources are located in over 60 countries and regions, including Africa, North America, Asia, the Middle East, and South America. Of these, Africa has the largest phosphate reserves, as it holds more than 80% of the world's phosphate rock resources. According to the United States Geological Survey (USGS), the worldwide reserve of phosphate was $7 \times 10^{10}$ t at the end of 2017, an increase of 2.9% over 2016 levels. Countries and regions with phosphate reserves greater than $1 \times 10^{9}$ t include Morocco and the Western Sahara, China, Algeria, Syria, Brazil, South Africa, Saudi Arabia, Egypt, Jordan, Australia, the United States of America, and Finland. These countries account for 96.6% of global phosphate reserves. In particular, the phosphate reserves of Morocco and the Western Sahara, mainly located in western Morocco, account for $5 \times 10^{10}$ t, 71.4% of the global total [4], whereas China's phosphate reserves account for 4.7% of the global total.

3.1.2 Global phosphate production

Global phosphate production exhibits extremely high market concentration. In 2017, global phosphate rock production was $2.63 \times 10^{8}$ t, which is 3.1% higher than that of the previous year. According to USGS statistics, there are 19 countries (regions) that produced more than $1 \times 10^{6}$ t of phosphate rock in 2017, with 4 countries (regions) producing more than $1 \times 10^{7}$ t of phosphate rock. The latter include China ($1.4 \times 10^{8}$ t, or 53.2% of the global total), the USA. ($2.77 \times 10^{7}$ t, 10.5% of the global total), Morocco and the Western Sahara ($2.7 \times 10^{7}$ t, 10.3% of the global total), and Russia ($1.25 \times 10^{7}$ t, 4.8% of the global total). The total phosphate rock production of these four countries (regions) was $2.07 \times 10^{8}$ t, which accounts for 78.8% of the global phosphate rock production. According to calculations based on USGS data, the average grade of phosphate rocks worldwide varies between 30% and 31%. Most countries produce phosphate rocks with phosphate graded at approximately 30%. Phosphate rock found in Russia, Brazil, South America, Finland, and Togo has a higher phosphate grade of approximately 35%, whereas that from the USA and Australia tends to have phosphate grades below 30%. In 2017, the global reserves-to-production ratio (R/P) of phosphate resources was 266; this implies that the global demand for phosphate will be safely met for a long time to come.

3.1.3 China's domestic phosphate rock consumption

China is the world's largest consumer of phosphate rocks, used predominantly for the production of phosphate fertilizers. Phosphate fertilizer production has increased rapidly in China since the beginning of the 21st century (as depicted in Fig. 1) [4]. China's self-sufficiency rate for the supply of phosphate rocks was 66.5% in 2000, rising to 95.6% in 2008. By 2009, China changed from a net importer to a net exporter of phosphate rocks. In 2016, 15.8% of the phosphate fertilizers produced by China were being exported, making China a significant contributor to the global growth of food production.

### 3.2 Phosphate demand forecasts

Based on China's contemporary consumption patterns, future growth in the country's consumption of phosphorus rocks will be largely driven by the domestic production of phosphate fertilizers. This is due to the rapid pace of agricultural development in China, where agricultural land is generally phosphorus-deficient. Furthermore, there is significant demand from China's neighboring countries and regions for Chinese phosphate fertilizer exports.

The "Recommended international advanced agricultural science and technology plan" (a "948" project), forecasts that between 2010 and 2050 China's annual phosphate fertilizer demand will range from $1.1 \times 10^{7}$ t to $1.2 \times 10^{7}$ t (in 100% $P_2O_5$ equivalent; the same applies below), which corresponds to an annual phosphate rock demand of 3.85

DOI 10.15302/J-SSCAE-2019.01.018

× $10^7$ t – 4.2 × $10^7$ t (in 30% $P_2O_5$ equivalent; the same applies below). Hence, the cumulative quantity of phosphate rock required for the predicted quantity of phosphate fertilizer production in China over the next 42 years (2009 – 2050) will be 1.8 × $10^9$ t – 2 × $10^9$ t. Xun et al. predict that China's phosphate demands will peak between 2020 and 2025, with a total phosphate rock demand of approximately 7 × $10^7$ t at this point [5].

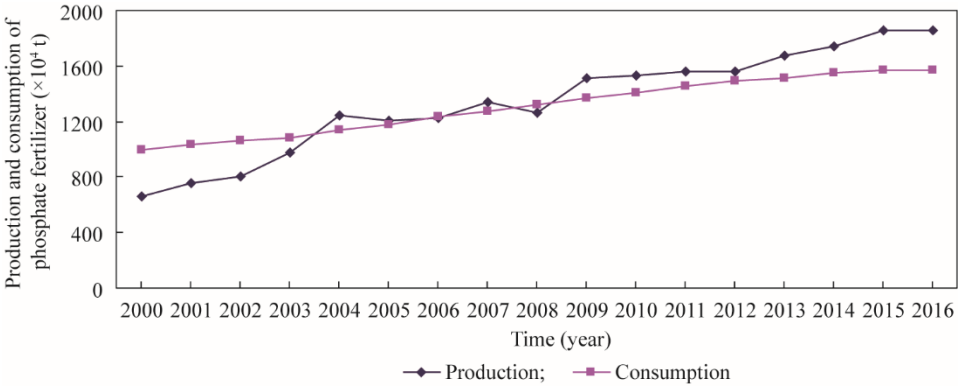


**Fig. 1.** Comparison between the production and consumption of phosphate.

In this work, China's phosphate rock demands are predicted using the sigmoid growth curve, based on the analysis of food production - chemical fertilizer usage, chemical fertilizer usage - phosphate fertilizer usage, and population - food production relationships since 1990 in China. The ratio between Chinese food production and related chemical fertilizer usage has varied consistently between 10:1 and 11:1 since 2000, without significant fluctuations. The proportion of $P_2O_5$ in chemical fertilizers is approximately 1/4, and this proportion is increasing slowly over time. Food production per capita historically increases in waves: it decreased from 365 kg/person in 2000 to 355 kg/person in 2001, and then increased again to 446 kg/person by 2016 (Fig. 2).

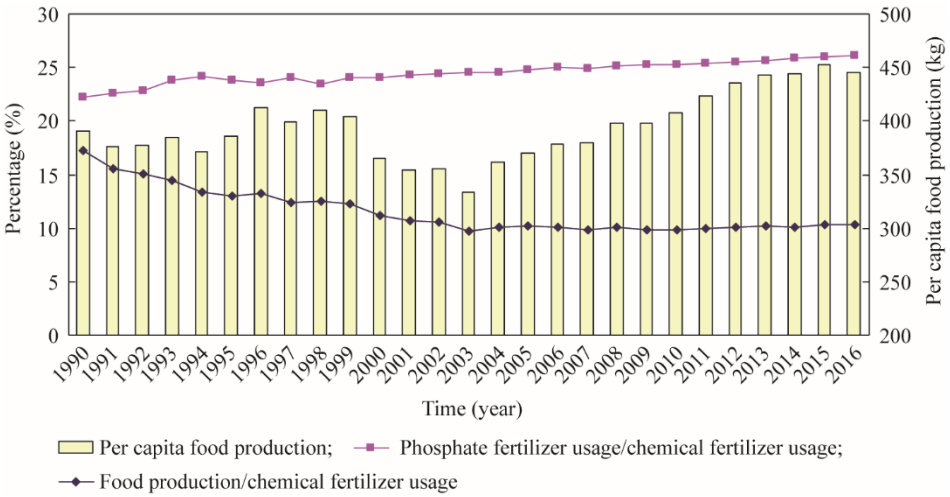


**Fig. 2.** Trends in per capita food production, phosphate fertilizer usage/chemical fertilizer usage, and food production/chemical fertilizer usage.

As phosphate fertilizer is the most significant driver of phosphate rock consumption, to predict China's phosphate rock demands accurately it is necessary to first predict the phosphate fertilizer demands. The demand for phosphate rocks may then be calculated according to the proportion of phosphate rock in phosphate fertilizers. In such predictions, it is necessary to define the ratio between food production and chemical fertilizer usage, and also the proportion of phosphate fertilizer present in chemical fertilizers. Based on the trends shown in Fig. 2 for the proportion of phosphate fertilizer in chemical fertilizers, the predicted percentage of phosphate fertilizer likely to be present in chemical fertilizers was set to 26.5%, 27%, 27.5%, and 27.5% in 2020, 2030, 2035, and 2050, respectively. In this work, China's phosphate rock demands were predicted for two different scenarios: firstly, the low-demand scenario, i.e. the minimum phosphate rock demand required for the development of the Chinese economy, and secondly, the high-demand scenario, where China's economic development is assumed to generate a higher demand

for phosphate rocks.

3.2.1 Predictions for the low-demand scenario

In this scenario, the ratio between food production and chemical fertilizer usage in China is assumed to be 11:1. The sigmoid growth curve is then used to predict the resulting phosphate fertilizer demand (Fig. 3). Based on the proportion of phosphate fertilizer to China's consumption of phosphate rocks, the phosphate rock demand is estimated to be $6.745 \times 10^7$ t in 2020, $7.309 \times 10^7$ t in 2030, $7.556 \times 10^7$ t in 2035, and $8.333 \times 10^7$ t in 2050. In addition, China's cumulative phosphate rock demands over the period from 2017 to 2050 is calculated to be $2.2 \times 10^9$ t.

3.2.2 Predictions for the high-demand scenario

In this scenario, the ratio between food production and chemical fertilizer usage is assumed to be 10:1. The sigmoid growth curve is then used to predict China's phosphate fertilizer demands (Fig. 3). Based on the proportion of phosphate fertilizers to China's consumption of phosphate rocks, the phosphate rock demand is estimated to be $7.42 \times 10^7$ t in 2020, $8.774 \times 10^7$ t in 2030, $8.905 \times 10^7$ t in 2035, and $1.07 \times 10^8$ t in 2050. China's cumulative phosphate rock demand over the period from 2017 to 2050 will be approximately $2.7 \times 10^9$ t.

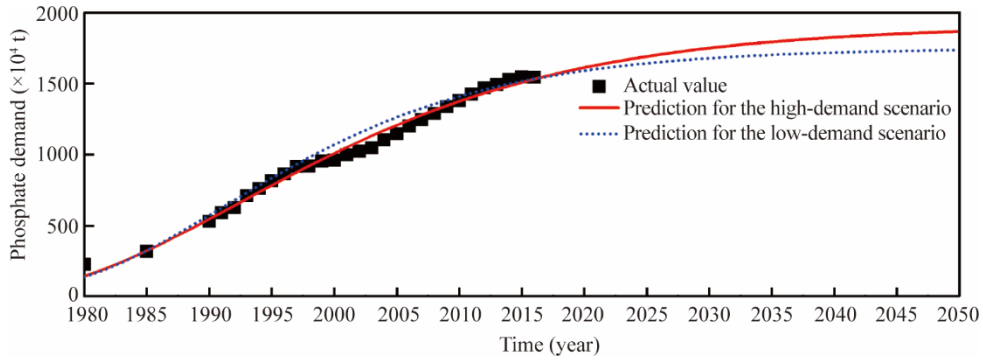


**Fig. 3.** Prediction of China's phosphate fertilizer demands.

## 4 The problems of phosphate exploitation in China

### 4.1 Excessively high production levels and insufficient reserves

In 2017, the phosphate R/P of China was only 24, which is less than 10% of the global level. China is now supplying 53.2% of the world's phosphate demands from a mere 4.7% of the world's total phosphate reserves, a level of phosphate production that is not sustainable given the available resources. Furthermore, China's phosphate R/P is decreasing more rapidly than that of any of the other major phosphate-producing countries, due to the relative paucity of this resource in China; China's phosphate R/P has declined by 58.6% since 2010, which is more than twice the global average (Table 1). Despite several contemporary phosphate deposit discoveries in China, the phosphate R/P remains at risk.

**Table 1.** Comparison between the primary phosphate-producing countries of the world in terms of phosphate R/P.

| Country/region | 2010 | 2017 | Change/% |
|---|---|---|---|
| Morocco and the Western Sahara | 1923 | 1852 | –3.7 |
| China | 57 | 24 | –58.6 |
| Algeria | 1100 | 1692 | 53.8 |
| Brazil | 62 | 309 | 400.0 |
| South Africa | 652 | 833 | 27.8 |
| United States of America | 54 | 36 | –32.7 |
| Worldwide | 369 | 266 | –27.9 |

### 4.2 Challenges posed by concentrated phosphate resource distribution and severe overproduction levels

China's phosphate resources are mainly located in the central and western regions, including Hubei, Yunnan, Guizhou, Sichuan, and Hunan. Hubei, Yunnan, and Guizhou boast the largest deposits, accounting for almost 60% of China's total phosphate reserves. China's reserve of phosphate-rich rocks (specifically $P_2O_5 \geq 30\%$) is also concentrated in Hubei, Yunnan, and Guizhou. From a geographical perspective, Yunnan and Guizhou are both

DOI 10.15302/J-SSCAE-2019.01.018

landlocked provinces, which adds to the difficulty of phosphate rock transportation; Hubei is the exception as it borders the Yangtze River via Yichang. Furthermore, the highest consumption of phosphate fertilizers occurs in northeastern and eastern China. Consequently, the bulk of phosphates mined in the south needs to be transported to the north, whereas phosphates mined in the west are usually transported to the east [6]. The necessity for long-distance transport of raw materials and the related costs are detrimental to the phosphate fertilizer industry, but these are not the only challenges the industry faces. In 2017, China's phosphate rock production was $1.2 \times 10^8$ t, which is more than twice the effective domestic demand. Moreover, based on the demand-prediction calculations in this work, China's phosphate rock production capacity currently significantly exceeds the domestic demand. In addition, China's phosphate mining and post-processing industries lack market concentration, and are inefficient, environmentally damaging, and prone to causing geological disasters. Furthermore, the industry faces heavy tax burdens [7,8].

## 5 A strategy for the development of China's phosphate resources

### 5.1 Stringent controls on phosphate production capacity

Phosphorus is one of the three major nutrients considered both indispensable to, and irreplaceable for, crop growth. Furthermore, phosphate resources are strategically important to China due to the extremely important role they play in securing domestic food production capacity. Therefore, the conservation of phosphate resources and the management of phosphate supplies to ensure sustainability are matters of utmost importance, as they concern the country's future food security.

At present, China's production of phosphate rocks greatly outstrips the domestic demand, and the production capacity is still growing, driven by the demands of a strong export market. Sustainability requires China to impose much stricter control on phosphate production capacity and expansion (both the production of phosphate rock and that of phosphate fertilizers). Moreover, technologically obsolete production infrastructure should be abolished to improve technological standards and the related efficiency of the Chinese phosphate industry [9]. In this regard, the first step is to significantly raise the environmental standards for market entry, thereby simultaneously reducing the growth of production capacity for phosphate rocks and phosphate fertilizers, and reducing the negative environmental impact of production. Secondly, obsolete production capacity should be eliminated by imposing new process requirements, eliminating low-tech production capacity with high pollutant emission rates. Furthermore, research and development should be conducted on high-value-added products and fertilizers that are easily absorbed by food crops. Thirdly, steps should be taken to refine the joint management mechanisms of the five major phosphate-producing provinces, and to support efforts to increase industry concentration or form alliances between phosphate enterprises. This would bring order to phosphate development and limit China's production of phosphates.

### 5.2 Fully utilizing global phosphate resources

Phosphate resources are non-renewable by nature. As China is a very populous country, its food demands will continue to grow over time, and China's food-industry phosphate demands will grow concomitantly. At the current rate of phosphate rock depletion, China will experience phosphate shortages from the year 2050, posing a direct threat to the country's food security. China should act preemptively, by, for instance, initiating international partnerships to take advantage of resource globalization and maximize the use of globally available phosphate resources in order to slow the depletion of China's phosphate resources and safeguard China's phosphate-dependent future food security.

The phosphate resources of China, Morocco, and the Sahara account for more than three-quarters of the world's phosphate reserves. Based on China's previous experiences in the international potash fertilizer industry, the establishment of a strategic phosphate resource alliance between China and Morocco could help to improve cooperation between these countries and form a complementary relationship of practical significance for the development of China's phosphate industry. To avoid unproductive competition between domestic enterprises in international partnerships, domestic enterprises should form business alliances or multinational companies to develop the resources of phosphate-rich countries. This would convert the resource advantages of these countries into economic advantages, thus improving the standard of living of the local population as well as addressing China's phosphate resource sustainability problems.

## 6 Conclusion

It is predicted that China's cumulative demand for phosphorus rock between 2017 and 2050 will be approximately

$2.2 \times 10^9$ t – $2.7 \times 10^9$ t. At present, China's capacity for phosphate production greatly exceeds its domestic needs, and is projected to continue to do so. Additionally, China is supplying more than half of the global phosphate market despite drawing on only 4.7% of the world's total phosphate reserves. Consequently, China's phosphate R/P is decreasing rapidly, and it is clear that the intensity of phosphate exploitation in China is much too high. Therefore, China should take preemptive measures to prolong the viability of its phosphate supplies. These measures includes the imposition of stringent controls on production capacity to limit phosphate production, and the strategic organization of better utilization of global phosphate resources.

## References

[1] Li W, Gao H, Luo Y J, et al. Status, trends and suggestions of phosphorus ore resources at home and abroad [J]. China Mining Magazine, 2015, 24(6): 6–10. Chinese.

[2] Kong L Z, Li Y H. Phosphorus ore analysis [J]. Geology of China, 1988 (1): 17–20. Chinese.

[3] Information Center of Ministry of Land and Resources. World mineral resources annual review 2016 [M]. Beijing: Geological Publishing House, 2016. Chinese.

[4] National Bureau of Statistics of the PRC. Statistical yearbook of People's Republic of China (2001—2017) [M]. Beijing: China Statistics Press, 2001—2017. Chinese.

[5] Sun X H, Chen C L, Wang G S, et al. The prediction of phosphate rock demand in China [J]. Acta Geoscientica Sinica, 2015, 36(2): 213–219. Chinese.

[6] Zhang S J, Xia H D, Tang W L, et al. Current status and sustainable development of phosphorite resources in China [J]. China Mining Magazine, 2014, 23(S2): 8–13. Chinese.

[7] Chang S j, Zhu J Y, Liu Y, et al. Situation of the world's phosphate resources [J]. Industrial Minerals & Processing, 2010, 39(9): 1–5. Chinese.

[8] Jin L F, Zhou H D. Research on exploitation and utilization and sustainable development of phosphate resources in China [J]. China Population, Resources and Environment, 2016, 26(S1): 417–420. Chinese.

[9] Nie K S. The analysis of resource and environmental constraints of China's phosphate resources demand situation [J]. Low Carbon World, 2016 (22): 42–43. Chinese.