Resources Policy 43 (2015) 11–18

Contents lists available at ScienceDirect

Resources Policy

journal homepage: www.elsevier.com/locate/resourpol

# Production forecast of China's rare earths based on the Generalized Weng model and policy recommendations

Xibo Wang [a,b], Yalin Lei [a,b,*], Jianping Ge [a,b], Sanmang Wu [a,b]

[a] School of Humanities and Economic Management, China University of Geosciences, Beijing, China
[b] Key Laboratory of Carrying Capacity Assessment for Resource and Environment, Ministry of Land and Resources, Beijing, China

ARTICLE INFO

*Article history:*
Received 3 September 2014
Received in revised form
10 October 2014
Accepted 10 November 2014
Available online 28 November 2014

*Keywords:*
Rare earths
Generalized Weng model
Production forecasting
By mine types
Policy recommendations

ABSTRACT

China is currently the largest producer of rare earths in the world, mining at least 90% of world total production. Because of China's dominant position in global rare earths production and the constant development of rare earths terminal industries, the study of China's rare earth supply trends has gradually been a hot topic of world interest. However, the literature shows that previous research has mainly focused on the estimation of rare earth supply and its influence based on experiential judge of current and premonitory new rare earth production capacity, rather than on quantitative modeling. The results are usually estimations of the productions of near future rather than longer term. Forecasts by mine types are particularly rare. Considering the different applications and demands of different rare earth elements, the Generalized Weng model, a widely used quantitative model in exhaustible resource forecast, is adopted in this study to predict the production of the three major rare earths in China (namely, mixed rare earth, bastnasite and ion-absorbed rare earth) before 2050. The results show that production of mixed rare earth will peak in 2014 at 62,757 t, followed thereafter by an annual decline of 2%; production of bastnasite will peak in 2018 at 32,312 t, preceded by an annual increase of 1.67% and followed by an annual decrease of 4%; production of ion-absorbed rare earth will peak in 2024 at 45,793 t, preceded by an annual increase of 1.72% and followed by an annual decrease of 4%. Based on these findings, Chinese government should enforce environmental and resource exhaustible taxes soon and different domestic regulations for different rare earths according to their different production potential. Countries without resource endowments should make efforts to develop rare earth recycling technologies and seek substitutes for rare earth resources, in addition to keeping good international trading relationships. Countries with some kind of rare earths should start or restart their rare earth mines to gradually reduce dependence on China's supply.



## Introduction

Rare earth elements (REEs) are performing important functions in our everyday life with their wide use in a range of products (McLellan et al., 2013). Meanwhile rare earths (REs) are also indispensable elements in modern industry with the uses in new energy, new materials, energy conservation, environmental protection, aerospace, and electronic information industries because of their unique physical and chemical properties. To protect the environment and ensure sustainable supply, the Chinese government implemented a series of policies to limit production and export. After several initiatives since 2006 to restrict the supply, the United State, the European Union, and Japan challenged China as lawsuit for violating provisions of its membership in the World Trade Organization (Ministry of Commerce People's Republic of China, 2014). It is easy to see from the lawsuit case that rare earth resources have been one of the targets of world competition accompanied by continuous development in rare earths-related industries.

There are currently 110 million tons of REEs proven reserves globally. Half of these reserves are located in China, with Russia accounting for another 17.3% and the United States for 11.8%. Sizeable deposits are also found in Brazil, India, Australia, Canada and Greenland (Wübbeke, 2013). The United States was the leading producer of rare earths from 1940s to mid-1980s, when it provided the majority of REs to the rest of world from the Mountain Pass mine in California which is one of the best minable deposits in the world (Gschneidner, 2011; Morrison and Tang, 2012). With the abundant and low-price REs supplies from China, Mountain Pass was unable to compete. Moreover, given the mine's

* Correspondence to: School of Humanities and Economic Management, China University of Geosciences Rm.504, Administrative office building, Beijing,100083, China. Tel.: +86 10 82323525; fax: +86 10 82321006.
*E-mail addresses:* wangxibo406@gmail.com (X. Wang), leiyalin@cugb.edu.cn (Y. Lei), gejianping@cugb.edu.cn (J. Ge), wusanmang@cugb.edu.cn (S. Wu).

http://dx.doi.org/10.1016/j.resourpol.2014.11.002
0301-4207/

increasing ecological costs as a result of a halt in chemical processing in 1998 on the back of a series of wastewater leaks, operations ended in 2002 (Currie, 2012).

China gradually has entered the international market for rare earths since the 1980s, and China's rare earth production has maintained an absolute leading position since 1986. During the 1990s, China's REs production increased sharply (He and Lei, 2013). China's overall rare earth mine production has almost become synonymous with global production since 2004. Obviously, China has become the world's largest producer, user, and exporter of REs in the recent decade with 97% share of global RE production (Massari and Ruberti, 2013).

With the constant development of rare earths terminal industries, the study of China's rare earth supply trends has gradually been a hot topic of world interest. However, literatures show that previous researches have mainly focused on the estimation of rare earth supply and its influence based on experiential judge of current and premonitory new rare earth production capacity, rather than on quantitative modeling. The results are usually estimations of the productions of near future rather than longer term. Forecasts by ore types are particularly rare.

Considering the exhaustible nature of rare earths and different applications and demands of different rare earth elements, the Generalized Weng model, a widely used quantitative model in exhaustible resource forecast, is adopted in this study to predict the production of the three major rare earths in China (namely, mixed rare earth, bastnasite and ion-absorbed rare earth) before 2050 and policy recommendations for different countries have been proposed based on the research results.

## Literature review

### *Prediction of exhaustible resources*

Exhaustible resources and energy are the basis of national economic development. The prediction of exhaustible resources and energy production is of profound significance, in that it not only assists governments to work out long-term resource and energy strategic plans but also helps to maintain sustainable social and economic development. Prediction of exhaustible resource production has its origin in oil sector. By middle of 20th century, methods of predicting field-level production were used in evaluating producing fields (Arps, 1945). In the 1950s and 1960s, curve-fitting techniques were used to forecast production (Hubbert, 1956). After the oil crisis of 1973, elevating resource depletion was to be a topic of vigorous theoretical exploration (Krautkraemer, 1998). And finally, the 1970s and 1980s saw increasing focus on econometric modeling of oil discovery and extraction (Walls, 1992). After that, the three techniques were applied to production prediction of other exhaustible resources and proved to be very effective for this purpose. Nevertheless, Brandt contends that all three techniques have its defect. For example, theoretical exploration and econometric model require the quantification of a large number of relationships and correlations, often in the face of conflicting or nonexistent data (Brandt, 2010). The curve-fitting technique is too dependent on original curves of event where no more flexibility of adjustment exists to variables. However, compared with the other two methods, the curve-fitting technique is the least data needed, particularly in the case of China's REs where the relevant data are especially difficult to get.

Among curve-fitting techniques, many scholars have adopted the Hubbert model (a typical bell curve model, which was first proposed by Hubbert) in production forecasting of energy (Bartlett, 2000; Hubbert, 1956; Zittel, 2007; Höök and Aleklett, 2009; Höök et al., 2010; Lin and Liu, 2010). After the Hubbert model, a variety of Hubbert-like curve-fitting models appeared, two among which are the Gaussian model (Bartlett, 2000; Brandt, 2007) and the Gompertz model (Moore, 1962, 1966). These models share properties of the Hubbert method while relaxing or altering some of its assumptions. Chinese scholars put forward the HCZ model (Feng et al., 2008; Hu et al., 1995) as well as the Generalized Weng model (Chen and Hu, 1996; Lv et al., 2012; Tang et al., 2009; Qiang et al., 1995), based on their studies of the curve-fitting techniques. These two models have mainly been used by Chinese scholars in their later research.

### *Prediction of REEs*

Because of the extensive application of REEs and the important position of China's RE reserves and production, studies on RE production have been increasing. Kingsnorth reported that the RE supply of other countries apart from China will increase significantly during 2011–2015, based on an analysis of the foreign RE companies' production and operation planning, RE research programs in these companies, and Japan's overseas RE investment projects. They also pointed out that the global RE supply will exceed the demand after 2013, and China's share of the supply will decrease (Kingsnorth, 2010b). Kingsnorth predicted that by 2014, China's RE production will reach 160,000–170,000 t (Kingsnorth, 2010a). Chen Zhanheng reported that foreign RE production capacity will exceed 170,000 t after 2015 by evaluating the rare project investment of all continents, and China's RE production will only account for 64% of global supplies if the foreign RE projects proceed as planned and domestic RE production can be maintained at 85,000 t as achieved in 2013. He also reported that foreign RE demand will be at least 80,000 t in 2015, and the lack of foreign supply of REs will reach 18,000–50,000 t if China's export quotas are set between 32,000 t and 35,000 t (Chen, 2011). Zheng Minggui by analyzing the reports of ≪Situation and Policies of China's Rare Earth Industry≫ and ≪Critical Rare Earths≫ and combined with the distribution of globe Rare Earth reserves predicted that China's share of the world's RE supply would be reduced to 77% by 2013 and reduced to 43% by 2017 (Zheng and Chen, 2012). In the case of China's restrictions on RE exports, Castor indicated that the Mountain Pass RE Mine in US may be reopened, and its RE output depends on China's export restrictions, price increase, and the growth of domestic demand and other factors (Castor and Hedrick, 2006). Based on China's Rare Earth Development Plan (2009–2015) and media reports, Wübbeke analyzed China's rare earth export policy and the development trend of China's rare earth terminal industry and indicated that by 2015, there will be no new RE mine projects and predicted that by 2015, China's RE output will be maintained between130,000 t and150,000 t and exports will be less than 35,000 t (Wübbeke, 2013). Hurst explored the history of rare earth elements and China's current monopoly of the industry, including possible repercussions and strategic implications if rare earth elements supply was to be disrupted and mentioned that by the middle of the next decade, China's RE output is expected to reach 160,000 t per year (Hurst, 2010). Based on documentary Research Methods, He and Lei point out that U.S. re-emerging REs industry will lead to a significant impact of RE supply surplus in total on future global and its internal REs demands. Nonetheless, the global including U.S. demand of Heavy REEs will still rely on China's supply (He and Lei, 2013).

### *Research orientations*

By reviewing the previous literature, some research orientations have been found. First, many quantitative models have been used in exhaustible resources forecast for a long time, especially the curve-fitting techniques. However, each method has its own