Resources, Conservation & Recycling 125 (2017) 208–217

Contents lists available at ScienceDirect

Resources, Conservation & Recycling

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

Full length article

Assessing maximum production peak and resource availability of non-fuel mineral resources: Analyzing the influence of extractable global resources

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ARTICLE INFO

Keywords:
Hubbert peak
Mineral depletion
Non-fuel minerals
Mineral resources

ABSTRACT

Among the existing methodologies to assess future availability of mineral resources, the Hubbert peak model is a direct approach that can provide useful information about non-fuel mineral depletion using BAU production trends. Using lithium as a case study, the influence on the fluctuations on extractable resources has been analyzed. Accounting only for conventional lithium resources, the peak is only delayed less than two decades even if the most optimistic resources values are doubled. Additionally, using resources information obtained mainly from USGS data, the maximum production peak of 47 mineral commodities has been estimated. For two of them, the maximum theoretical production peak has already been reached, 12 could have theirs in the next 50 years and a total of 30 commodities could reach their maximum production peak in the next century. Many factors can influence these values, changes in future extraction trends, ore grade, exploration and new discoveries and more accurate data on resources. With this information the most crucial elements (i.e. those peaking soon) can be identified and be used to put more emphasis on policies regarding sustainable use of non-renewable commodities.

1. Introduction

It is common knowledge that this century is characterized by a global increase of material extraction at worldwide level. For instance, according to the United States Geological Survey (USGS) reports, the total world production of iron ore has doubled in the last ten years and the production of lead has increased by 50% in that same period. Combined with the global population growth, which is projected to increase to 11.2 billion by 2100 (United Nations, 2015), the concern about the availability of raw materials is on the rise. As the mineral production and reserves of those minerals are concentrated in very few regions and their availability is crucial, in the last years many organizations and governments are focusing on analyzing the availability of raw materials from different perspectives.

One way to assess the future availability of mineral commodities is by using the Hubbert peak approach, a methodology that has been extensively used to evaluate fossil fuel peak production and depletion and that can also be applied to non-fuel minerals. First, Meadows et al. (1972) applied these exponential-like curves to the production of several commodities. The cycle of copper was analyzed by Roberts and Torrens (1974) and Arndt and Roper (1977) focused their study on 35 minerals both in the United States and at global level. All these studies relied on early reserves estimates and consumption rates that were neither accurate nor reliable. In the last decades, more studies have been made with better assumptions. For instance, Bardi and Pagani (2008) examined the world production of 57 minerals and found that in 11 cases the production had clearly peaked and was already declining, such was the case of mercury, tellurium, cadmium and selenium among others. Glaister and Mudd (2010) used historical production of platinum group metals (PGM) to estimate the maximum peak of production with reserves and reserve plus reserve base, occurring in 2037 and 2049 respectively. Additionally, it has also been applied to the phosphorous cycle, with peak estimations occurring before 2035 (Cordell et al., 2009).

In this paper a comprehensive analysis will be carried out using availability of lithium as a case study, stressing the shortcomings of the methodology and showing the influence of the resources data in the maximum production peak of minerals. Then, once the methodology is proven useful for mineral resources, it is applied to assess the production trends of all remaining mineral commodities using available resources information.

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http://dx.doi.org/10.1016/j.resconrec.2017.06.009
Received 30 March 2017; Received in revised form 13 June 2017; Accepted 13 June 2017
Available online 26 June 2017
0921-3449/

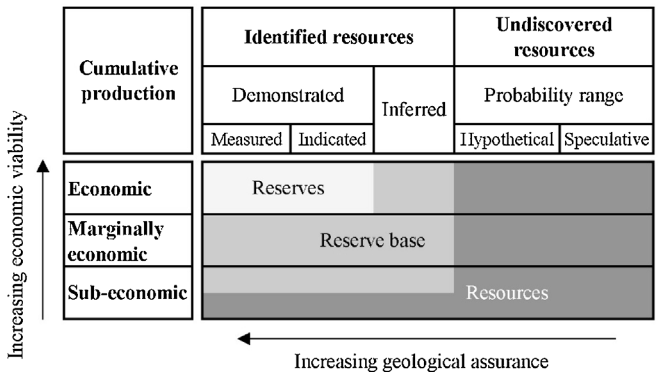

Fig. 1. Classification of mineral reserves and resources (own elaboration using USGS classification).

2. Mineral availability

To be able to analyze future mineral availability, it is necessary to have information regarding supply and demand. Usually supply refers to the amount of raw materials that is made available to the industry and depends mainly on the extraction of minerals from the Earth and the secondary supply coming from recycling. Extraction is limited by the amount of minerals present in the crust, which depends on the total resources, reserve base and reserves (Fig. 1).

Resources are the best estimate of the total availability of each commodity in the crust in such form and amount that economic extraction is currently or potentially feasible. The reserve base, also called extractable global resource, is that part of an identified resource that meets specific physical and chemical criteria (ore grade, quality, depth, etc.); it includes those resources that are currently economic, marginally economic and subeconomic. Finally, reserves are defined as the part of the reserve base that can be economically extracted in a determined time. Therefore, as the technology and commodities prices change, reserves vary as well. If new production technologies are developed, unattainable resources can become reachable or profitable. In this classification, the reserve base is probably the most reasonable approximation of the quantity of a resource that can be produced over time.

Reserve and resource estimations usually come from inventories of mining companies as well as from national geological services. The problem with these is that they are limited by many factors, such as price of the commodities, lack of exploration, geologic limitations and demand. As the type of information and the data reported can substantially vary, there are several initiatives that are trying to unify the reports, developing a standard which includes useful information about exploration results, mineral resources and reserves for investors and professional advisers. In fact, the "Pan-European Standard for Reporting of Exploration Results, Mineral Resources and Reserves", known as the PERC Reporting Standard, first developed in 2006, and later published in 2008, had this as main purpose (PERC Reporting Standard, 2013). Other attempts have been made in Australia, being the JORC Code the first published in 1989 (JORC Code, 2012), followed, among others, by CIM in Canada (CIM, 2010). The first international standard was published in 2006 by CRIRSCO using the standards that existed in previous models (CRIRSCO, 2013). Even if all the definitions of reserves and resources are similar in all the reporting templates, CRIRSCO has harmonized the codes into a common international reporting standard.

Currently, one of the most used sources for reserve and resource information is the United States Geological Service, as it compiles information from mines and deposits from all over the world and for all the mineral commodities. Yet, the information is sometimes incomplete, and as 2009, the reserve base estimations are no longer provided. Table 1 shows the reserves and resources information for the commodities selected in this study for the years 1995 and 2015. When resources information was not available for the selected years, such as for antimony and gold, reserve base values have been included instead (USGS, 2009).

For several minerals, resource information made available by USGS has been calculated or estimated using different assumptions. For instance, for cadmium estimated world resources were calculated using the cadmium content in identified zinc resources, assuming 0.3% cadmium content (USGS, 2009). In the case of cobalt resources, identified world terrestrial cobalt resources are about 25 million tonnes, but the total number also includes 120 million tonnes found in manganese nodules and crusts on the floor of the Atlantic, Indian, and Pacific Oceans (USGS, 2016). For copper, identified resources contain about 2.1 billion tonnes of copper, but the undiscovered resources contain an estimated 3.5 billion tonnes (Johnson et al., 2014). Magnesium can be recovered from different sources, identified world magnesite and brucite resources represent over 12 billion tonnes. Resources of other magnesium-bearing minerals and brines are estimated at billions of tonnes, but no specific data are provided (USGS, 2016). Therefore, in this paper only figures of the resources of magnesite and brucite have been used. In the case of titanium, the resources for 2015 account for all titanium minerals (anatase, ilmenite, rutile) while around 92% of the titanium consumption corresponded only to ilmenite (USGS, 2016).

As reserves and resources information concerning rare earth elements (REE) is not always reported disaggregated by element, the resources information that has been used are the estimations from Haque et al. (2014), that analyzed the percentage of rare earths in various ore deposits and the known resources of rare earth containing ores. Additionally, other sources have been consulted as well when USGS did not provide accurate information neither on reserve base nor on resources. This is the case of beryllium resources, which were estimated by the USGS to be at least 80,000 t, while other estimations place them at 400,000 t (Emsley, 2001), or germanium, with total world resources estimations of 400,000 t (Frenzel et al., 2014). For indium, manganese, silver and tin, USGS does not provide numbers of global resources, therefore the estimation of available extractable amounts carried out by Sverdrup and Ragnarsdottir (2014) was used.

As shown by Table 1, both reserves and resources are dynamic data and can change over the years according to different factors. They may be reduced as ore is mined, as the extraction feasibility diminishes or increase as additional deposits are discovered or are more thoroughly explored. They can also change in response to demand, politics and socioeconomic trends. Specifically, mineral reserves are very influenced by price fluctuations and also depend on the companies immediate decision-making, therefore making reserve data very volatile and unreliable to evaluate mineral depletion (Drielsma et al., 2015). For instance, the reserves data for phosphate rock have increased six-fold in the last twenty years. Fig. 2 demonstrates that nickel reserves have increased over time, while nickel resources have remained constant. Still, for other minerals, such as chromium or manganese, reserves data have been decreasing even if prices have increased.

Even so, the average trend is that reserves and resources data is gradually increasing, but it must be taken as a first approach that can change over time.

In this paper resources figures are going to be used as the reference to calculate maximum production peaks with the Hubbert peak model as they are less dependent on changes in commodity prices and technology than reserves.

3. Theoretical background

There are multiple approaches to assess future availability of natural resources and measure their depletion degree. One of the simplest approaches is the reserves-to-production ratio, R/P or RPR ratio. This ratio represents the number of years of which the current level of production can be sustained by the available reserves, dividing the