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Rare earth elements mining investment: It is not all about China

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ABSTRACT

China was in the past the main driver when analysing rare earth prices and their market, since it commercialised around the 90% of the world's supply. After a cut in its exports during 2010 and 2011, rare earth prices dramatically spiked. The world's reaction to this fact was the development of a huge amount of mining projects outside China, many of whom failed when prices fell again. Nevertheless, several of them survived.

This paper analyses in first place the future trend of rare earth elements prices in order to contrast the stable tendency forecasted by different providers of price assessments and market data. Secondly, it studies in deep five ready-to-go rare earths mining projects around the world: Nechalacho Project (North-west Territories, Canada); Zandkopsdrift Project (Northern Cape, South Africa); Bear Lodge Project (Wyoming, USA); Kvanefjeld Project (Southern Greenland); and Dubbo Zirconia Project (New South Wales, Australia). The main purposes being to give an "order of magnitude" both technical and economic of this specific mining industry; to provide a tool for investors, potential investors and professional advisers addressing rare earth mining investment analysis; and to facilitate the development of preliminary economic assessments of future rare earth mining projects. These aims will also help to fight against several systemic problems of the rare earth market: lack of trust, market opacity, and short versus long-term approaches and profit orientation.

Conclusions clearly show that despite the complexity of rare earth mineral deposits and the fact that their mining operation usually includes different by-products, the evaluation of rare earth mining investments does not present much more difficulty than in the case of single element mining projects. Forecasted prices used in these economic studies are the Achilles' heel of nowadays rare earth mining investment analysis.

Finally, although differences in demand of different rare earth elements will make really difficult to achieve "a priori" a market in balance, the five studied projects are anticipated to cover approximately the third part of the total rare earth consumption in the world. When their dysprosium oxide production was analysed, the resulting proportion for the most critical rare earth element based on its role in clean energy together with its biggest supply risk was almost the same, something optimistic regarding the achievement of a balanced market outside China.

1. Introduction

There are fifteen rare earth elements (REE) or lanthanides, that are usually classified into light rare earth elements (LREE) and heavy rare earth elements (HREE), based on their atomic weight. The LREE are: lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), and samarium (Sm). The HREE are: europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), and lutetium (Lu). On the other hand, scandium (Sc) and yttrium (Y) although they are not true REE they are often categorized as such due to their similar chemical and physical properties together with their occurrence in the same deposits. Yttrium is lighter than the light rare earth elements, but it is included in the heavy rare earth group because of its chemical and physical associations with heavy rare earths in natural deposits.

REE follow approximately the Oddo-Harkins law: the single porcen-

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tual composition within the different minerals where they can be found (bastnaesite, monazite, etc.) is smaller as the atomic number increases. Thus, LREE are more abundant than HREE (Kilbourn, 1993).

While named rare earths, in fact they are not that rare as they are relatively abundant but unusual to be found in quantities enough to enable an economic mineral development. Moreover, as they are "essential to civilian and military technologies and to the 21st-century global economy, including green technologies (e.g., wind turbines and advanced battery systems) and advanced defence systems." according to the Worldwide Threat Assessment (US Intelligence Community, 2013), to develop sources outside China that accounts for more than 90% of world production has become critical.

The European Union has categorised rare earth elements within the list of "critical raw materials" (Chapman et al., 2013). Both LREE and HREE were assessed as critical with approximately the same economic importance but having the HREE a much bigger supply risk, due to the influence of China in terms of global supply: 99% of HREE and 87% of LREE.

The British Geological Survey also ranked them on the top of their "Metals Risk List" (British Geological Survey, 2015) with a relative supply risk index of 9.5, in a scale that runs from 1 to 10 according to various factors: production concentration, reserve distribution, recycling rate, substitutability, governance (top producing nation and top reserve-hosting nation) and companion metal fraction.

The U.S. Department of Energy (2011) in the study entitled "Critical Material Strategy" reviewed REE based on their role in clean energy together with the supply risk. They identified neodymium, europium, terbium, dysprosium and yttrium as critical rare earths (CREE) for the short and the medium-term. Praseodymium was also included in the list because of the use of didymium (Nd + Pr) as a major raw material for NdFeB permanent magnets. Dysprosium was the CREE with the biggest importance to clean energy and supply risk in the medium-term: 2015–2025. It was followed by terbium, with a lower importance to clean energy, and the neodymium, with a lower supply risk.

REE are used in a wide variety of applications (ERECON, 2014): permanent magnets (20%), polishing (15%), fluid-cracking catalysts (13%), other metallurgy (10%), batteries (8%), glass (7%), phosphors (7%), autocatalysts (6%), ceramics (5%), and other (8%).

Also according to ERECON (2014) the estimated total rare earth consumption for 2012 was 113,250 t of rare earth oxides (REO), while the European rare earth consumption was 8050 t REO for 2010. The historical rare earth consumption between 2006 and 2014 was more or less constant and the demand is projected to increase (Massari and Ruberti, 2013).

Although differences in demand of different REE will make really difficult to achieve a market in balance (Binnemans et al., 2013b; Elshkaki and Graedel, 2014), the five projects that will be studied hereafter are anticipated to produce around 41,100 tpa REO, so these projects alone will cover approximately the third part of the total rare earth consumption in the world.

Finally, there is no current substitutability of rare earths for about the 45% of nowadays applications, while for another 45% substitutability is at high cost and/or loss of performance. Moreover, Binnemans et al. (2013a) pointed out that up to 2011 the REE recycling rate was less than 1%, something that suggest the potential to offset in the future a significant part of REE primary extraction. This is the case of the Solvay's plant in France that recycles lamp phosphors with a high content of CREE (Golev et al., 2014).

This paper analyses in first place the evolution and trends of REE prices focusing on dysprosium oxide, as its importance to wind power technology together with the biggest supply risk among REE has incentivized development economies to undertake actions in order to support its supply (Baldi et al., 2014). Neodymium is also very important for clean energies but is far more abundant than dysprosium.

Secondly, it studies in deep five ready-to-go REE mining projects around the world: Nechalacho Project (Northwest Territories, Canada); Zandkopsdrift Project (Northern Cape, South Africa); Bear Lodge Project (Wyoming, USA); Kvanefjeld Project (Southern Greenland); and Dubbo Zirconia Project (New South Wales, Australia). The main purposes being to give an "order of magnitude" both technical and economic of this specific mining industry; to provide a tool for investors, potential investors and professional advisers addressing REE mining investment analysis; and to facilitate the development of preliminary economic assessments of future REE mining projects.

These aims will also help to fight against several systemic problems of the rare earth market: lack of trust, market opacity, and short versus long-term approaches and profit orientation, as identifyed by Klossek et al. (2016).

In fact, several years ago Chen (2011) warned that strong cautions should be adopted on REE mining investment due to the huge amount of projects that were being developed worldwide. Also, McLellan et al. (2014) stated that the concerns of companies and governments that rely on REE as an economic pillar had been focused on their price, the supply restrictions, and the availability of deposits out of China.

2. Rare earth elements prices

European prices for REE are mainly quoted in USD/kg and are basis in-warehouse Rotterdam, duty unpaid. Oxides are priced in powder, and metals in lingots (Argus Media Ltd, 2015). REE are usually traded in oxide form as oxides have an unlimited shelf life and are more widely used in the manufacturing industry.

HREE are more sought-after: e.g. dysprosium and terbium oxides are quoted around 300–500 USD/kg, while neodymium, europium and praseodymium oxides are quoted around 50–90 USD/kg.

In Fig. 1 the baseline situation of dysprosium oxide prices (purity: Dy_2O_3/TREO min. 99.5%) and europium oxide prices (purity: Eu_2O_3/TREO min. 99.99%) in Europe are presented. Purity refers to a trace metals basis of total rare earth oxides (TREO). Both REE present similar baseline situations although they belong to very different price ranges.

As several REE are oversupplied, prices can be even much lower. That is the case of yttrium, cerium, lanthanum and samarium oxides that quote below 7 $/kg (Source: HEFA Rare Earth, 2015).

As China was in the past the main driver when analysing rare earth prices and their market (commercialising around the 90% of the world's supply), after a cut in exports during 2010 and 2011, rare earth prices dramatically spiked. The world's reaction to this fact was the development of many REE mining projects outside China, many of whom failed when prices fell again (Barakos et al., 2016). Nevertheless, several of them survived. In 2013 and 2014 stockpile purchases from the US Defense Logistics Agency and China's State reserve Bureau added to the underlying demand, although the quantities were not enough to halt prices sliding lower (Argus Media Ltd, 2014).

Based on this fact and trying to estimate the future trend of REE prices and to contrast the stable tendency forecasted by different providers of REE price assessments and market data, we will analyse dysprosium oxide prices with time series models, following the methodology described in (Krzemień et al., 2015). @RISK 6, from Palisade Corporation (Ithaca, New York), was used for the simulation of the time series models.

The baseline situation of dysprosium oxide (Fig. 1) shows through its autocorrelation function (ACF) that both media and variance are non-stationary. Thus we need to find the transformations needed to produce stationarity.

A square root transformation was applied in first place in order to reduce right skewness. It was followed by a second order differencing detrend (differences between successive first differences) as the series is non-stationary both in the mean and in the variance.

Finally, an additive deseasonalization (a seasonal correction to each

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