Pathways to achieve resilience in rare earth magnets supply chain

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1. Introduction

The energy transition to a low-carbon system can stress natural resources by significantly increasing the demand for rare earth elements (REE) [1, 2]. Neodymium (Nd), belonging to the REE group, has gained prominence in recent years due to the growing demand for Nd-Fe-B magnets and its globally unbalanced supply [3,4]. Such magnets facilitate the development of high technology, such as wind turbines and electric vehicles, that encourage the transition to a low-carbon economy. However, Nd is one of the top ten most critical raw materials in terms of supply risk and its relevance in socio-economic metabolism. Furthermore, mining and processing of rare earth are associated with high levels of soil and water pollution, intensive use of chemicals, and release of greenhouse gases [5].

Currently, mining remains the main source of REE [6] and it is estimated that only 1% of all discarded REE is recycled [7]. So, there is a need to develop sustainable strategies to mitigate the environmental footprints of the energy transition [8]. Also, it is important to mitigate Nd supply disruption risks to foster the resilience of rare earth magnet supply chains. In this context, circular strategies can be implemented to deal with the challenge of REE scarcity [1, 9].

Thus, this study aims to indicate ways to achieve resilience in the rare earth magnets supply chain based on aspects of the circular economy. The relevance of this research is associated with the importance of this material for the industrial and economic sectors worldwide, due to its unique chemical and physical properties. The results of this review should help guide future research, indicating which practices should be further studied to close the materials loop and improve resource efficiency.

2. Method

The proposed method was structured in two macro stages: theoretical analysis, and conceptual development. The first stage consists of a Systematic Literature Review (SLR) on rare earth magnets and how they relate to CE. A search of articles was carried out in scientific databases of Scopus and ISI Web of Science with keys terms associated with three main elements: “circular economy”, “rare earth”, and “neodymium”. Scopus and ISI Web of Science databases were selected due to their dominant use in scientific mapping and broad coverage of circular economy journals. This procedure was performed on December 2022. No chronological restrictions were used in this selection. Because it is an emerging topic, the authors chose to consider both articles and conference papers.

The search procedure mapped 164 articles distributed among the scientific bases, of which 153 articles were found in Scopus, and 164 were obtained from the ISI Web of Science. Next, the data referring to the articles were extracted and analyzed using the Mendeley

software. Inclusion and exclusion criteria were applied to compose the final set of studies. The scope was restricted to studies that address a strict relationship between circular economy strategies and Nd, Nd-Fe-B magnets, or REE in general (articles that dealt specifically with an REE, other than Nd, were disregarded). Thus, after this step, 74 articles were selected and evaluated. The second stage, conceptual development, aimed to categorize the studies according to the adopted circular practices.

3. Results

The annual distribution of the selected papers indicates that the relationship between circular economy and rare earths is an emerging topic, 63% of the studies are from 2021 and 2022. After the content analysis, it was possible to recognize four main research subjects of studies: i) REE recovery from post-consumer products, ii) REE recovery from industrial waste, iii) Circular strategy discussions, and iv) Assessment and decision support tools. The focus of academic research has been directed to the recovery of REE (31%), such as Nd, from post-consumer products by routes such as pyrometallurgy, hydrometallurgy, and biohydrometallurgy. The second large group comprises studies that employed or developed assessment and decision-support tools (30%). Following, research on REE recovered from industrial waste (20%) circular strategies (19%) had similar representativeness in this portfolio.

4. Discussion and Conclusion

The recovery of REE from alternative sources was the strategy most discussed by the portfolio studies. Several authors have explored REE recovery routes on a isolation way. However, holistic approaches need to be developed to study the interaction between strategies and their influence on the circularization of critical resources over time. The second conclusion from the literature review is the absence of LCA studies exploring the potential benefits of recovering rare earths from waste generated in the production of Nd-Fe-B magnets. We highlight the importance of making industrial waste effective as another source of rare earths, contributing to closing the loop on these resources. Still, the lack of discussion on the possibility of the product-service system adoption by the Nd-Fe-B magnet industry stands out. By conferring magnet ownership on the manufacturers, this strategy has the greatest potential to minimize rare earth consumption and waste generation. Magnet producers, researchers and customers can join forces in structuring this business model. Thus, to foster the resilience of the Nd-Fe-B magnets supply chain, future studies should be directed towards:

• The adoption of the product-service system by the Nd-Fe-B magnet industry should be discussed;

• The potential for direct reuse of Nd-Fe-B should be explored. Studies are needed to evaluate the effects of using recovered magnets in emerging technologies;

• The Recovery of REE process in the magnet manufacturing process must be consolidated to close the cycle of these resources;

• Industry and customers should collaborate to define product design requirements to facilitate the removal of magnets from post-consumer products;

• There is a need to develop and consolidate sustainable approaches to recovering REE from secondary sources. Biotechnological approaches are promising and should be explored considering technical, economic and environmental aspects;

• The public sector must provide financial support for the establishment of recycling processes, either through investments in infrastructure, tax incentives or establishing recycling targets;

• We also suggest that national systems should be created to consolidate information on the quantity, characteristics and location of products that use Nd-Fe-B magnets.

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