Criticality of rare earths for application in electric vehicles and wind energy in Brazil

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Abstract

Rare earth elements (REEs) are important components in technologies aimed at decarbonising the economy, such as electric cars and wind turbines. In 2010, China, the world's largest producer of these elements. The dependent countries on Chinese supply have suffered an increase of the prices and were worried about the provision. Thus, several criticality studies were carried out to evaluate whether these elements could be a bottleneck for the consolidation of the fleet expansion plans for electric vehicles and wind energy. Brazil has the second largest reserve of these elements and intends to create a rare earth productive chain with products with high added value. Therefore, the present study has the objective of evaluating if the REEs could become a bottleneck for the Brazilian plans to expand the fleet of electric vehicles and wind energy.

1 Introduction

The rare earth elements (REEs) are technically defined as the fifteen elements of the lanthanide family - elements with the atomic number (Z) between 57 and 71 - plus two associated, yttrium (Y) and scandium (Sc). The term “earth” is due to the fact that throughout the 18th and 19th centuries, when such elements were isolated, in the form of oxides, at that time, “earth” designated metallic oxides (eg alkaline-earth metals). The term "rare", on the other hand, was due to the late discovery of the first elements and their complex separation (GUPTA e KRISHNAMURTHY, 2005; SOUSA FILHO e SERRA, 2014).

However, contrary to what one imagines when reading “rare earth”, these elements are abundant in the crust, cerium (Ce) and lanthanum (La), for example, are more abundant than nickel (Ni) and lead

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(Pb), respectively . While neodymium (Nd) has a higher concentration in the crust than copper (Cu). In the less abundant group, such as dysprosium (Dy) and erbium (Er) have a higher occurrence than gold (Au) (MCLENNAN, 2001; RUDNICK e GAO, 2003).

The REEs are critical components for the operation of many devices that are part of our daily lives such as: smartphones, cars, computers, televisions and light bulbs. The unique properties present in these elements are essential for the expansion of so-called green technologies, which aim to reduce dependence on non-renewable fuels and improve energy efficiency. With the constant increase in energy demand and the search for cleaner sources, REEs have gained economic, political and academic interest in recent years. Mainly after China, the world's largest exporter of REEs since the 1990s, announced a reduction in export quotas in 2010.

The importance of REEs in the industry lies in the fact that many of these elements are present in wind power systems, electric motors and high-efficiency lighting systems, hybrid and electric vehicles, as well as in the aerospace and defense industries. REEs resources are distributed all over the planet, including Brazil, where the second largest reserve in the world is present. Although they are abundant in the earth's crust, they are found in low concentrations, making their extraction costly and technically difficult. In fact, the term "rare" was not given by the degree of scarcity, which ends up generating some confusion. He was assigned to this group because of the late discovery of these elements.

One of the main problems, or possibly the cause of the others, is the concentration of production in a few countries, where the largest producer is responsible for more than 85% of world production. So, to supply the demand for REEs, the nations with the biggest economies - USA, Japan and EU countries depend on imports.

The forecast of increased demand for green technologies in the energy and transport sectors is noticeable. Expansion plans for the implantation of wind turbines for the generation of electric energy and for the hybrid and electric car fleet are outlined by several countries. Many of the technologies applied nowadays are dependent on permanent magnets that use REEs for their manufacture.

One example is the Maglev Cobra project, a vehicle based on magnetic levitation designed for urban transport, developed by the Superconductor Applications Laboratory (LASUP), at the Federal University of Rio de Janeiro (UFRJ). The vehicle, which has advantages when compared to the wheel-rail and VLT (light rail vehicle) systems (SOUSA, 2016), uses REEs magnets along its track. In this case, the magnet used is produced with neodymium (neodymium-iron-boron – NdFeB).

After the announcement of the reduction of export quotas by the Chinese government, prices, which were previously modest, reached peaks with an appreciation of more than 600% for some elements such as dysprosium, europium and terbium, between 2010 and mid-2011 (MASSARI e RUBERTI, 2013). Part of the extreme rise in the price of REEs happened for reasons of speculation, as the expert explains LIFTON (2012).

There is a lot of uncertainty about the issues of REEs resource, exploration and market, since most of it is controlled by China, which was sometimes justified by environmental issues or by a possible shortage of internal supply, which may still have been motivated by an oversupply ZEPF (2013). The author also mentions that the information available in the reports and studies is based on incomplete or unreliable data, despite the large amount of published reports. The REEs offer data is basically provided by a source, which under scientific aspects is not reliable and cannot be proven by validation. This creates a space for discussing how reliable the supply-demand relationship is.

Regarding production, information on reserves and market values is almost not publicly available. United States Geological Survey data (USGS), they are the most used, but they do not clearly present their sources. Several consulting firms offer reports that analyze the REEs market, but access to these documents is paid, making it difficult to obtain the information.

With the rise in prices triggered by the 2010 crisis, many REEs exploration projects in new mines were launched in different parts of the world. Speculators with little experience in the REEs market bought small mining companies, which caught the attention of investors, but the projects did not go ahead. Lack of knowledge about the market led investors to analyze the REEs as a whole, not considering that each element has its own market and its own application, as he explains LIFTON (2012).

For many REEs production exceeds demand, only a few are critical or rare indeed (LIFTON, 2012). What happens is a problem of balance in the supply, since these elements are not found in isolation (BINNEMANS et al., 2013).

Brazil, which was a relevant producer until the mid-twentieth century and currently does not produce, has plans to create a value chain for the production of REEs with high added value products, such as neodymium (Nd) magnets and, thus, position as a worldwide supplier of the material. In this way, there is the opportunity to create a sustainable value chain, which can be a competitive differential in relation to other countries.

The REE sector is at risk of short-term shortages of some elements due to growing demand, particularly in clean energy technology applications such as wind. With supply constraints due to the complex and unpredictable market, many elements have been identified as critical. Recycling and reuse, which currently have almost no investment in research and development, emerge as promising solutions to face scarcity.

The difficulties of inserting itself as a relevant actor in the REEs value chain stem mainly from the control of the market that China manages to exercise. In fact, the creation of a national value chain aims to guarantee the supply of REEs for application in green technologies and other technologies without depending on the external market. To meet Brazil's expectations, a multidisciplinary research on the subject is necessary, since little is said about the subject in national research centers. In addition, the country has plans to expand the fleet of hybrid and electric vehicles and wind energy, increasing the importance of this study in academia. Thus, the demand for REEs, which are present in NdFeB magnets, tends to increase. Thus, the problematization of this study arises: would the REE be a bottleneck for the execution of national plans?

The objective of this work is to verify whether the supply of REEs present in NdFeB magnets would be an obstacle to the execution of plans to expand the fleet of hybrid and electric vehicles and wind energy in Brazil by 2050. For this, establish the sectorial panorama of the REEs, as well as verifying the existing technological applications help to fulfill this proposal.

2 Methods

The methodology of the present study was based on MOSS et al. who used the Critical Metals in the Path towards the Decarbonization of the EU Energy Sector study. It consisted of a bibliographic search of papers using Portal Periódicos Capes as database, in addition to books, reports produced by national and international government agencies, business reports, law and regulations. In the first moment, the main articles about REEs present in journals and in several government agencies such as USGS and British Geological Survey (BGS) were identified. Reports and studies from the National Department of Mineral Production (DNPM), United States Department of Energy (US DoE), United States Environmental Protection Agency (USEPA), Joint Research Center (JRC), publications and presentations from national conferences and international, studies carried out by consultancies, conversations with specialists, among others, were also sources of research.

Thus, the analysis of the REEs market was performed based on the data and information collected. The main studies on criticality, scarcity, supply risk were surveyed, in addition to the data on the worldwide supply of REEs. The state of the art of the hybrid technologies, electric vehicles and wind farm was also identified. Thus, a scenario was defined based on the study “Greenhouse Gas Emissions-2050: Economic and Social Implications of the Government Plan Scenario” developed by CENTRO CLIMA/COPPE/UFRJ and in the National Energy Plan 2050 (NEP 2050) to project the expansion of the fleet of hybrid and electric vehicles and the generation of wind farm in Brazil. However, the number of REEs present in the neodymium magnet required for each of these applications was calculated. The REEs present on the magnet in addition to the neodymium are praseodymium (Pr), dysprosium (Dy) and terbium (Tb).

First, the main studies on criticality, scarcity, supply risk, in addition to data on the world supply of REEs were raised. The state of the art of technologies used in hybrid and electric vehicles and in wind energy generation was also identified. Finally, the role of creating the national REE production chain to guarantee the country's supply and be able to export value-added products to countries seeking supply alternatives was discussed.

To determine the number of hybrid and electric vehicles to be sold in Brazil by 2050, the considerations of the GHG emission scenario for the transport sector present in the study were adopted as a study IES-50. For the projection of sales of light vehicles of the automobile and light commercial type, the average growth rate of 3.43% p.a., from 2018 to 2050, of the IES-50 was adopted. For 2015 and 2016, data from the National Association of Automotive Vehicle Manufacturers (ANFAVEA, 2017). In view of the 2016 economic crisis, there was a 19.3% drop in the number of licenses for these vehicles. On the other hand, the sector forecasts a 2.4% growth (FENABRAVE, National Federation of Automotive Vehicle Distribution) at 4% (ANFAVEA) for this segment in 2017, so the same growth rate of 3.43% p.a. for the year 2017 (EXAME, 2017).

For hybrid cars, the IES-50 adopted a 0.05% share of sales in 2015. Then, linear growth was adopted until 2045, when this technology will reach a 90% share of sales. In 2050, the share of sales will be 82%, due to the greater share of electric vehicles. As for electric cars, the IES-50 adopted a share of 0.001% of sales in 2015. Then, a linear growth was considered until 2045, when it will reach a share of 10% of sales. From 2045 to 2050, an exponential growth in the share of sales was considered, in which this technology will reach 18% of the share in 2050.

According to Global EV Outlook 2016, BEV participated with 59% of the Electric Vehicle (EV) market in the countries analyzed in 2015 (IEA, 2016). On the other hand, in Europe, in 2015, the participation of PHEVs of 60% of the total EV (JRC, 2016). Therefore, the share of BEV (Batery Electric Vehicle) and PHEV (Plug-in Hybrid Electric Vehicle) in the EV market, for the Brazilian reality, was considered 50% for each of them.

To project data referring to hybrid light commercials, the start of commercialization in 2020 was considered, with a share of 1.99% of sales, as in the IES-50. However, the document indicates an average growth of 119% in sales until 2045, when such technology would reach 100% of the share. However, such growth margin proved absurd when calculated, extrapolating, in 2026, the total number of light commercials sold. Therefore, for this projection, an average growth of approximately 21% p.a. in sales was considered in order to reach 100% of the share of sales in 2045.

With the results of the projection of sales of hybrid and electric vehicles, the necessary quantities of NdFeB magnets to meet the demand in the 2050 scenario were calculated. Demands for each of the REEs of the magnet were also calculated.

For the projection of the amount of REEs to be used in wind turbines for 2050 in Brazil, considerations were adopted from the reference scenario of the IES-Brazil 2050 Project for the energy supply sector. According to this, the share of wind energy could reach 11% of the total installed capacity in 2050, making it the second main source of electricity generation.

In view of the iNCD measures, forecasts for the evolution of installed capacity by energy source were presented, where data were generated year by year through the average growth rate calculated every five years. The forecast is that wind energy will grow at an average of approximately 10% p.a. in the first five years. Between 2020 and 2050 this rate does not reach 4% p.a.

For this study, the difference between the current year's installed capacity and the previous year's installed capacity (= increased capacity in that year) was used as a reference, between 2025 and 2035, for example, the highest installed capacity will occur in the last year of the 5-year series, that is, in the years ending with “0” or “5”. Thus, the greatest expansion of capacity remains for the year under review.

This was a choice to bring the prediction closer to reality. If linear growth were adopted, in the 5 years of each interval the expansion would be the same in each one of them.

3 Results

3.1 - Electric vehicles

The results of the projection for electric vehicles in Brazil are shown in **Figure 1**. With the results of the projection of sales of hybrid and electric vehicles, the necessary quantities of NdFeB magnets to meet the demand in the 2050 scenario were calculated. Demands for each of the magnet's REE were also calculated. The results are shown in **Table 1.**

For comparison, the ratio between the total demand each year and the supply for each REE in 2015 was established. In 2040, for example, the demand for Nd for vehicle engines will be 528.8t, which represents 2.84% of world Nd production in 2015.

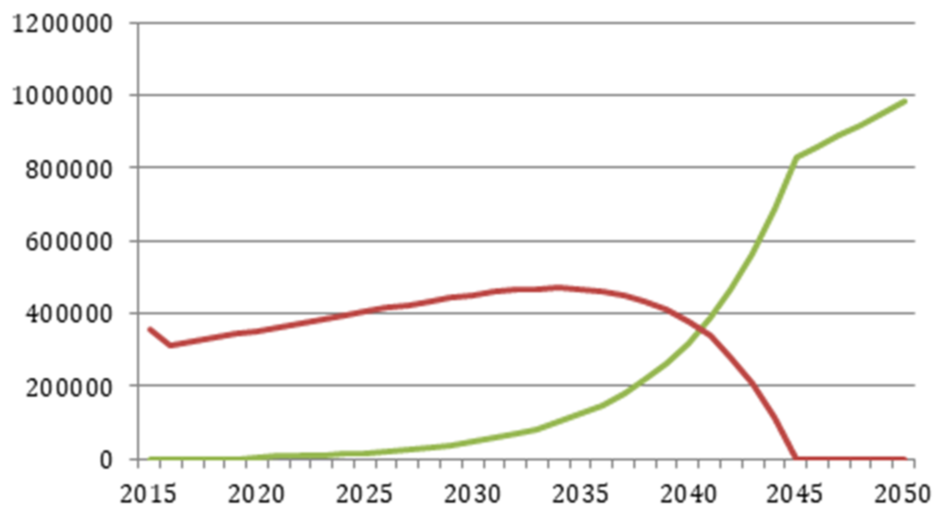

Figure 1: Graph of total sales of commercial vehicles (-Hybrids and -Others) until 2050

According to **Table 1**, the element that will present the worst scenario in 2050 will be dysprosium. For the transport sector in Brazil alone, demand would be 43% of all Dy produced in 2015. Of course, this estimate does not consider the increase in the supply of REEs. Furthermore, efforts to reduce the dependence of REEs on engines will bring positive results. This comparison serves to alert decision makers about a possible shortage in supply and, thus, seek alternatives, whether they are: reducing the use of these elements, replacing or even recycling.

	Nd total	% Nd*	Pr total	% Pr*	Dy total	% Dy*
2015	0.16	0.00%	0.05	0.00%	0.05	0.01%
2016	8.72	0.05%	2.91	0.05%	2.89	0.37%
2017	17.91	0.10%	5.97	0.10%	5.93	0.76%
2018	27.73	0.15%	9.24	0.16%	9.18	1.18%
2019	38.19	0.21%	12.73	0.22%	12.65	1.63%
2020	50.35	0.27%	16.78	0.29%	16.67	2.14%
2021	62.44	0.34%	20.81	0.36%	20.67	2.66%
2022	75.32	0.40%	25.11	0.44%	24.94	3.20%
2023	89.05	0.48%	29.68	0.52%	29.49	3.79%
2024	103.68	0.56%	34.56	0.60%	34.33	4.41%
2025	119.26	0.64%	39.75	0.70%	39.49	5.07%
2026	135.86	0.73%	45.29	0.79%	44.99	5.78%
2027	153.54	0.83%	51.18	0.90%	50.84	6.53%
2028	172.36	0.93%	57.45	1.01%	57.07	7.33%
2029	192.42	1.03%	64.14	1.12%	63.72	8.19%
2030	213.79	1.15%	71.26	1.25%	70.79	9.10%
2031	236.58	1.27%	78.86	1.38%	78.34	10.07%
2032	260.89	1.40%	86.96	1.52%	86.39	11.10%
2033	286.84	1.54%	95.61	1.67%	94.98	12.21%
2034	314.56	1.69%	104.85	1.84%	104.16	13.39%
2035	344.23	1.85%	114.74	2.01%	113.98	14.65%
2036	376.01	2.02%	125.34	2.19%	124.51	16.00%
2037	410.10	2.20%	136.70	2.39%	135.80	17.45%
2038	446.75	2.40%	148.92	2.61%	147.93	19.01%
2039	486.22	2.61%	162.07	2.84%	161.00	20.69%
2040	528.84	2.84%	176.28	3.09%	175.11	22.50%
2041	574.97	3.09%	191.66	3.35%	190.39	24.47%
2042	625.05	3.36%	208.35	3.65%	206.97	26.60%
2043	679.59	3.65%	226.53	3.96%	225.03	28.92%
2044	739.19	3.97%	246.40	4.31%	244.77	31.45%
2045	804.57	4.33%	268.19	4.69%	266.41	34.24%
2046	840.75	4.52%	280.25	4.90%	278.39	35.78%
2047	878.30	4.72%	292.77	5.12%	290.83	37.37%
2048	917.28	4.93%	305.76	5.35%	303.73	39.03%
2049	957.72	5.15%	319.24	5.59%	317.13	40.75%
2050	999.69	5.37%	333.23	5.83%	331.02	42.54%

*Comparison with estimated production in 2015 (considering only legal production)

Table 1: Future demand for REEs for application in hybrid and electric vehicle engines in Brazil

3.2 - Energy sector

The results of the projection for wind energy in Brazil are shown in **Figure 2**, graph of the evolution of the installed capacity of wind energy in Brazil. To calculate the total amount of NdFeB magnet required, the data in **Table 2** were used. The magnets used in wind turbines have a different composition from those used in electric vehicle engines, since the application conditions are not the same. **Table 3** presents data from the literature and those considered in this study.

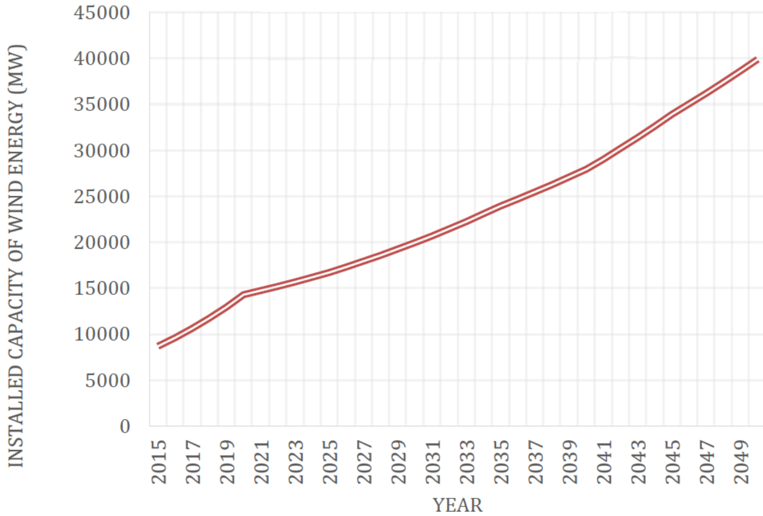

Figure 2: Projected growth of installed wind energy capacity by 2050

	DD-PMG	MS-PMG	HS-PMG
ZEPF (2013)	675	0.12	0,12
PAVEL et al. (2016)	0.65	0.16	0,08
Considered in the study	0.65	0.12	0.12

Table 2: NdFeB magnet mass per MW (t/ NdFeB/MW)

REE	ZEPF (2013)	LACAL-ARÁNTEGUI (2015)	Considered in the study
Nd	22.5	20.3-22.4	22
Pr	7.5	8.7-9.32	8
Dy	4.5	3.0-6.0	4.5

Table 3: Composition of NdFeB magnets used in wind turbines (% mass of REE in the NdFeB)

The demand for total REEs (**Table 4**), as well as in the analysis of hybrid and electric vehicles, was compared with the world production of REE in 2015. It is noted that, even using a relatively high amount of NdFeB magnet, its application in wind energy for Brazil's plans it does not bring great concerns.

	Nd total	% Nd*	Pr total	% Pr*	Dy total	% Dy*
2015	9.74	0.05%	3.54	0.06%	1.99	0.26%
2016	14.95	0.08%	5.44	0.10%	3.06	0.39%
2017	22.15	0.12%	8.06	0.14%	4.53	0.58%
2018	30.70	0.17%	11.16	0.20%	6.28	0.81%
2019	40.79	0.22%	14.83	0.26%	8.34	1.07%
2020	52.65	0.28%	19.15	0.34%	10.77	1.38%
2021	18.91	0.10%	6.88	0.12%	3.87	0.50%
2022	20.96	0.11%	7.62	0.13%	4.29	0.55%
2023	23.12	0.12%	8.41	0.15%	4.73	0.61%
2024	25.40	0.14%	9.24	0.16%	5.19	0.67%
2025	27.79	0.15%	10.11	0.18%	5.68	0.73%
2026	35.01	0.19%	12.73	0.22%	7.16	0.92%
2027	38.25	0.21%	13.91	0.24%	7.82	1.01%
2028	41.68	0.22%	15.16	0.27%	8.53	1.10%
2029	45.32	0.24%	16.48	0.29%	9.27	1.19%
2030	49.16	0.26%	17.87	0.31%	10.05	1.29%
2031	52.77	0.28%	19.19	0.34%	10.79	1.39%
2032	55.43	0.30%	20.16	0.35%	11.34	1.46%
2033	58.21	0.31%	21.17	0.37%	11.91	1.53%
2034	61.13	0.33%	22.23	0.39%	12.50	1.61%
2035	64.18	0.35%	23.34	0.41%	13.13	1.69%
2036	56.80	0.31%	20.65	0.36%	11.62	1.49%
2037	59.28	0.32%	21.56	0.38%	12.13	1.56%
2038	61.86	0.33%	22.50	0.39%	12.65	1.63%
2039	64.55	0.35%	23.47	0.41%	13.20	1.70%
2040	67.34	0.36%	24.49	0.43%	13.77	1.77%
2041	87.84	0.47%	31.94	0.56%	17.97	2.31%
2042	91.32	0.49%	33.21	0.58%	18.68	2.40%
2043	94.94	0.51%	34.52	0.60%	19.42	2.50%
2044	98.70	0.53%	35.89	0.63%	20.19	2.59%
2045	102.61	0.55%	37.31	0.65%	20.99	2.70%
2046	88.99	0.48%	32.36	0.57%	18.20	2.34%
2047	91.93	0.49%	33.43	0.59%	18.80	2.42%
2048	94.97	0.51%	34.53	0.60%	19.42	2.50%
2049	98.10	0.53%	35.67	0.62%	20.07	2.58%
2050	101.34	0.54%	36.85	0.64%	20.73	2.66%

*Comparison with the estimated production of 2015 (considering only the legal production)

Table 4: Total REEs demand

4 Conclusions

With the result of the vehicle fleet projections, it became clear that, in 2050, the Dy is the most critical, produced through the criticality matrix developed by the National Research Council (NRC). In that year, approximately 42.54% of the world production of the element in 2015 would be necessary to supply only the national needs in this application. As for the expansion of wind energy, the results were positive. Although turbines require a large amount of REEs per unit, for national plans this demand does not represent a significant step for world production.

Recycling can be an alternative to guarantee the supply of REEs. However, the technological difficulties in the processes, which are often inefficient, and the lack of incentives are the main problems. In addition, the amount required for these types of applications is high, so the waste to be recycled must contain a large volume of REEs to become viable, making it an advantageous alternative only if the cost of the material already recycled is lower or equivalent to that of original.

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