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# International perspectives on mining rare earths: a case study in the Southern Jiangxi Province, China

**Communication** | Editorial | Invited contribution | Perspective | Report | Review

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**Abstract**

The international profile of rare earth elements (REEs) has increased rapidly in recent years—highlighted by their importance in a wide range of applications including lasers, wind turbines, medical equipment, mobile phones, cars, electrical vehicles and defence equipment. Given the increasing demand for these minerals for crucial uses within the 'green economy', securing supply to the major consumers of REEs is essential. At the international level, the current dominance of China in known reserves, REE based processing, industries and international trade strengthens the country's importance in geopolitical terms. This article provides a background to REEs at the international level, focussing on mining REEs in southern Jiangxi province in south east China and highlights the upcoming challenges faced by the sector.

## Introduction

This article consists of two main sections: firstly the importance and geographical location of rare earth elements (REEs) globally will be discussed, and secondly the case study of an REE mining area in Dingnan county (Jiangxi Province) will be described; the case study [1] included field-work and work with a number of universities and government bureaux based in Nanchang, the capital of Jiangxi Province. A noticeable difference between REE mining in Dingnan county, as compared with REE mining in other countries including Australia and the US, is that in the former mining has been carried out on populated areas with agricultural activities.

## Rare earth elements (REEs)

Despite their name, REEs are commonly found in the Earth's crust. However, the extraction of individual REEs via mining and processing is problematic and requires the use of potentially polluting chemicals. REEs comprise the 15 elements known as lanthanides and the transition metal yttrium (Figure 1). Scandium, another transition metal, is sometimes considered a REE

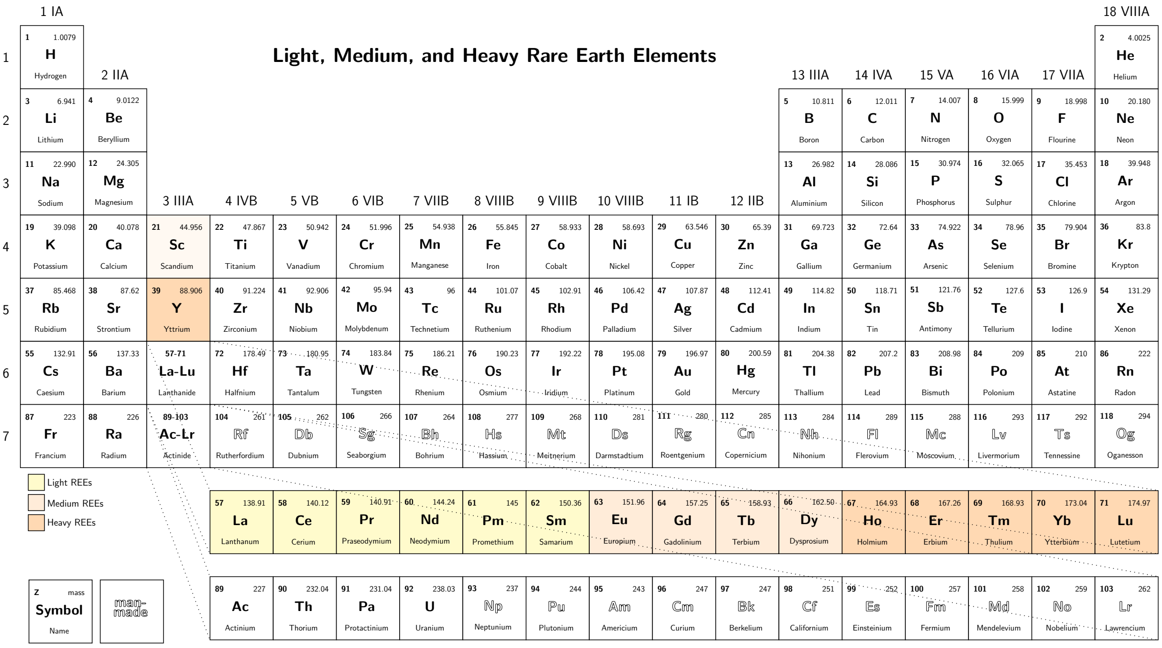


Figure 1: Periodic table showing heavy, medium, and light rare earths [1].

due to its presence in REE mineral deposits, but its status is subject to debate [1].

REEs are commonly divided into heavy (HREEs) and light REEs (LREEs) according to their atomic weights, and their association in mined deposits. For example, scandium and yttrium, which have a lower atomic weight than LREEs, are grouped with HREEs because of their paired electronic configuration: LREEs have unpaired electrons and HREEs have paired electrons [1]. Some divisions also include medium REEs (elements between europium and dysprosium).

## The International context

The REE mining and processing industry continues to be not only an important part of the development and manufacture of high-end technologies, but also a geopolitical tool in an increasingly unstable and unpredictable global market. The high-end technologies referred to will mostly be related to the development of 'green economy' and the transition towards low-carbon economies. There are several comprehensive reviews within the REEs sector; for example, the report from the British Geological Survey which includes information on REE deposits worldwide, their extraction and processing routes, the specification of uses in new technologies and substitutes, REE mining developments, and global trade [1]. Disruptions to supply chains caused by tariff changes and geopolitics pose important issues for the global REE economy [2].

Figure 2 shows estimates of the projected demand for REEs by end-use sector [2] and how the demand is divided across different REEs, while Table 1 summarises the overall demand for REEs by end-use sector [2, 3]. The existing and future demand for REEs is projected to increase, and the demand will be dominated by neodymium (Nd), terbium (Tb) and Dysprosium (Dy). These elements are required to manufacture magnets used in wind turbines and other applications for renewable energy globally.

There are two stages in the exploitation of REEs resources: the first is mining, which is mainly surface mining, and the second is the processing and extraction of individual REEs.

Figure 3 shows the overall distribution of REE mines, deposits and reserves globally. The main concentrations of these minerals are to be found in China and Australia, with other important reserves in Brazil, India, Malaysia, Russia and Vietnam.. Apart from these REE reserves, many other countries–like Burundi and Malawi, as well as Denmark (Greenland), Norway and Sweden–

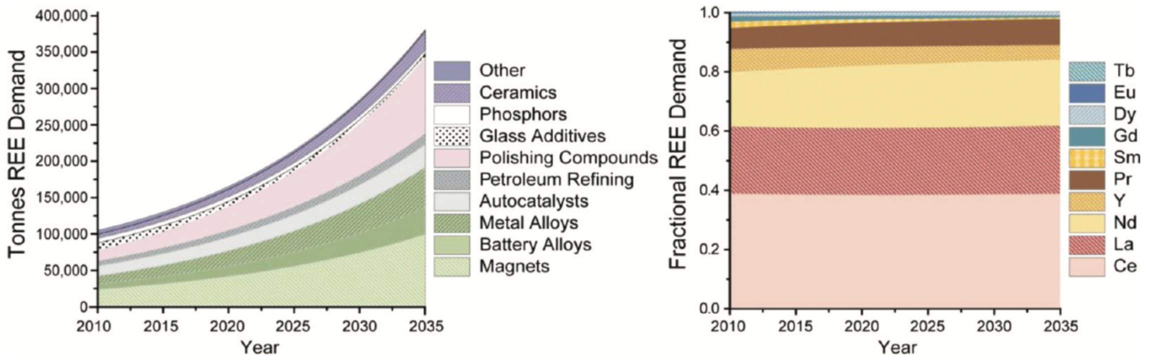


Figure 2: **Projected demand for REEs by end-use sector**. Reprinted with permission from [2]. Copyright 2020 American Chemical Society.

Table 1: Uses of key REEs by sector. *Italic*: REEs used in metallic state; **bold**: REEs used in oxidised state. Data from [3].

| Sector | REEs | Uses |
|---|---|---|
| Phosphors | **Eu, Y, Tb, Nd, Er, Gd, (Ce, Pr)** | LED, lasers, flat panel display, fluorescent lamps, Xray imaging, optical sensors, fibre optics |
| Catalyst and Chemical Process | **La, Ce, (Pr, Nd)** | Petroleum refining, automotive catalysts, diesel additive, water treatment |
| Ceramics and Glass | **Ce, La, Pr, Nd, Gd, Er, Ho** | Polishing media, UV resistant glass, thermal glass, capacitors, sensors, colourants, refractories, fuel cells, super-conductors |
| Metal alloys | *Ce, La, Pr, Nd, Y* | NimH batteries, Superalloys, Al-Mg alloys, steel |
| Magnets | *Nd, Pr, Sm, (Tb, Dy)* | Motors and genertors, HD drives, microphones and speakers, MRI machines, defence industry, magnetic refrigeration |
| Other | | Fertilisers, pigments, nuclear energy, medical tracers |

have these resources, but mining is currently exploratory or there is relatively small production. [4].

The dominance of China in the resourcing, mining and processing of REEs (Table 2) has increased the dependence of the rest of the world, particularly the US and the EU, who are the main importers, on REE supply from China. REEs are considered to be critical minerals and therefore of major importance to economic development and geopolitical strategy [5, 6]. Supply security is of crucial importance for the US [6], where REEs imported from China are employed in the defence industry. During the recent trade disputes between China and the US, China had threatened to curtail REE exports to the US, highlighting the geopolitical power these elements have [7].

The US, EU and other major users of REEs are prospecting for alternative, non-chinese sources of REEs in a number of countries including Norway, Sweden, and more recently Greenland. Initial geological exploration indicates that there are considerable deposits of REEs in Greenland–in many cases associated with uranium–and this attracted investments from both Australian and Chinese companies[1]. Exploitation may develop after environmental impact assessments have been carried out and the mining companies have received government approval.

[1]Chinese companies are increasingly investing in REE mining and REE resources outside of China in order to better conserve some of the national REE resources.

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Figure 3: **Global mining of REEs**. Reprinted from the US Geological Survey [4].

## Environmental risks and REE mining

The environmental risks associated with mining REEs, as with other surface mining, are associated with air pollution and soil and groundwater contamination, with consequent impacts on local human populations, biodiversity, agriculture and other land use (Table 3). The presence of radioactive elements, notably thorium and uranium and other LREEs, is a further risk at the processing level (water leachate, formation of dust); however the overall risks from radiation are considered to be small. A review from Ault and colleagues discusses further environmental and social aspects of REEs industries [8].

Table 2: Current reserves of REEs worldwide (in metric tons of rare earths oxide equivalent). Data from the US Geological Survey [4].

| **Country** | **Reserves** (*metric tons*) |
|---|---|
| China | 44 Million |
| Brazil | 22 Million |
| Vietnam | 22 Million |
| Russia | 12 Million |
| India | 6.9 Million |
| Australia | 3.4 Million |
| United States | 1.4 Million |

| Process | Element | Risk | Hazard level |
|---|---|---|---|
| Mining | Open Pit | Land consumption | – |
| | Waste rock storage | Leachate of rain water into groundwater (e.g. heavy metal contamination) | Medium |
| | Damming | Tailing dam collapse due to poor construction, overtopping, seismic event | High |
| Milling and Flotation | Impoundment areas: water basins with extraction chemicals and tailings (small-sized particles with large surface area) | Leachate of rain water into groundwater (e.g. heavy metal and radioactive contamination) | High |
| | | Land use | – |
| | | Dust (e.g. heavy metal and radioactive contamination) | Medium |
| Further processing | – | Air emission | Low |
| | – | Waste water | Low |

Table 3: Ecological risks at different steps of REEs mining. Data adapted from [9].

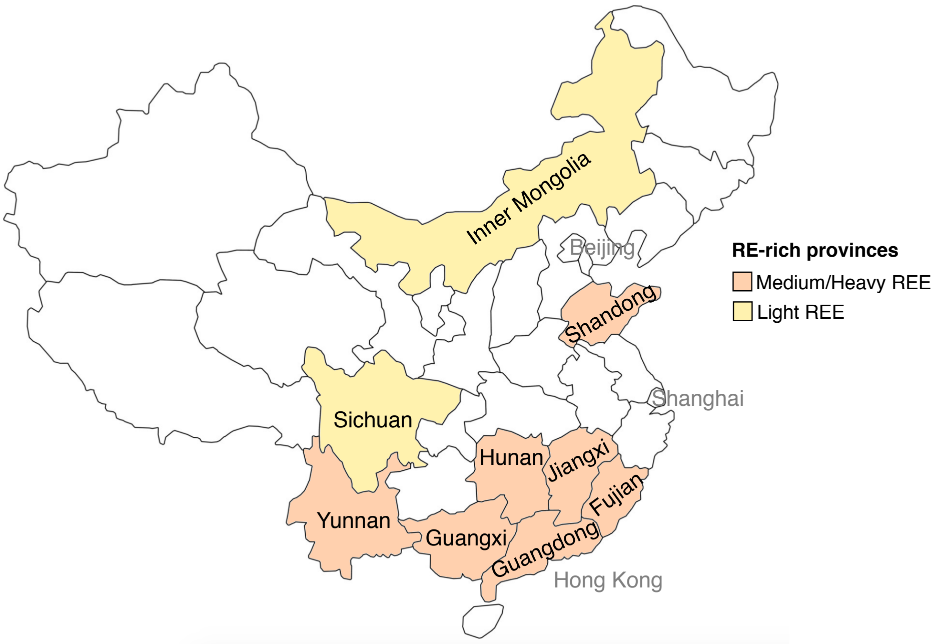


Figure 4: Chinese Provinces rich in REEs [10]. The class of the most extracted REEs is shown for each region.

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## REEs in China

The main deposits of REEs in China are found in the provinces of Fujian, Hainan, Jiangxi, Guandong and Guanxi in South East China (Figure 4) [10, 11]. In 2016, a non-profit organisation called China Water Risk compiled a comprehensive review of the Chinese REE extraction sector and its future challenges, including assessments of the resource base, market share, and the history of illegal mining and its environmental consequences [10].

The central government in China produces export quotas for REE production by province (Figure 5), although in some cases these quotas are circumvented by illegal mining and exports. Illegal activities have been stopped in large part by central government policing [10]. This measure has led to a fall in REE production in China, which resulted in Chinese imports of some REE ores from the USA, Myanmar, and Vietnam.

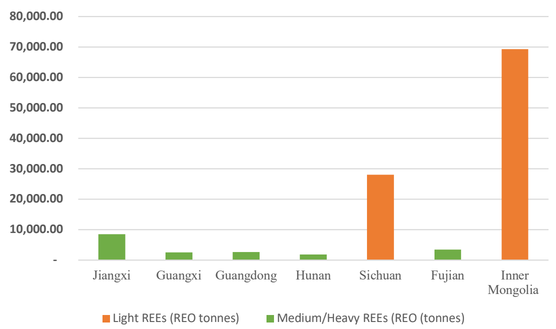


Figure 5: Control quotas for the production of REEs in China (2018) [12].

### *Rare earths mining in Jiangxi Province: background and costs*

This section is based on survey fieldwork commissioned by the Asian Development Bank (ADB) and which was in part managed by the author in 2018 in Dignan county, which is located in the south of Jiangxi province, one of the most important centres of REE mining in the province. The contrast between REE mining in Dingnan and other REE mining areas in northern China, Australia and the USA are the fact that the mining in Dingnan County–now ceased after government intervention–was carried out in a populated area with agriculture and other economic activities which were disrupted by REE mining.

The aim of the project in the Jiangxi province was to assess the impacts of REEs mining on the local physical, economic and ecological environments, as well as comparing the legal implications with other countries and international approaches to the remediation of mining areas. It was apparent that the remediation options for abandoned mines–including phasing and cost effectiveness–had not been comprehensively planned in the project area.

It is estimated that Jiangxi Province produces 38% of the total HREE and 50.3% of high grade REEs production in China [10]. These figures show how important REE mining and processing are to the Jiangxi and national economies via direct and indirect employment in mining and remediation: in fact, mining accounts for 4.4% of provincial GDP. The distribution of mining provincial GDP value by sub sector is shown in Figure 6.

The physical impacts of the REE surface mining in Ganzhou Prefecture (Jiangxi province) are illustrated in Figure 7, showing the the landscape before and after the mining activities. Estimates of the relationship between remediation costs and the sales income of the REEs industry in Ganzhou Prefecture in 2011 [14], show that while past remediation costs totalled US$ 5.8 billion, the sales income of REEs was only US$ 4.7 billion while the annual profit of Ganzhou's REEs industry was only US$ 0.3 billion over 10 years.

Abandoned REE mine sites–in what is a mainly rural area–continue to offer challenges for central and peripheral provinces. The contamination of REE surface mining in China and its impacts on resources, the environment, and public health have been noted by several scientists in China and internationally [15–17].

### *Rare earths mining in Jiangxi Province: environmental impact*

The main environmental impacts in the Jiangxi mining have been the movement of REE leachates from the surface mining into surface water courses and groundwater (Table 3). Contamination originated from both *in situ* mining and from tailing

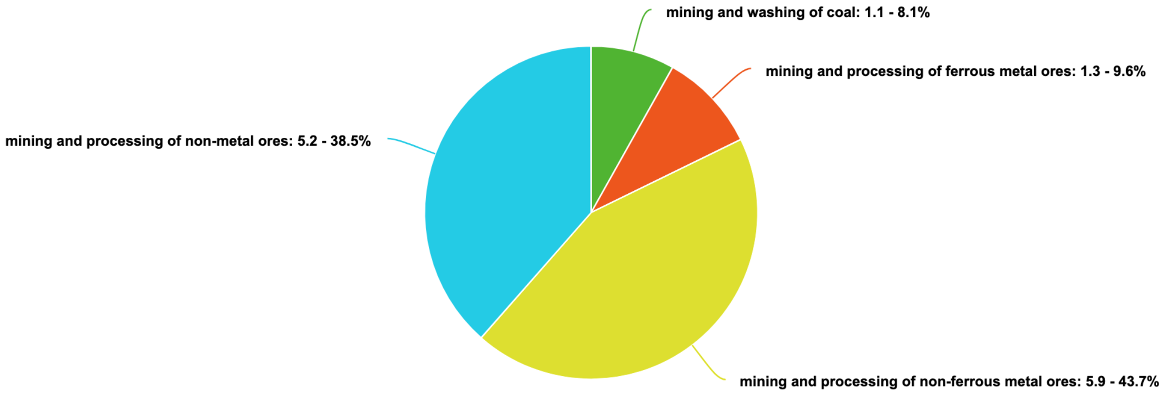


Figure 6: Contribution per extraction activity to the Jiangxi provincial GDP for the mining sector (13.5 Billion USD – 4.4 per cent of the total provincial GDP) [12].

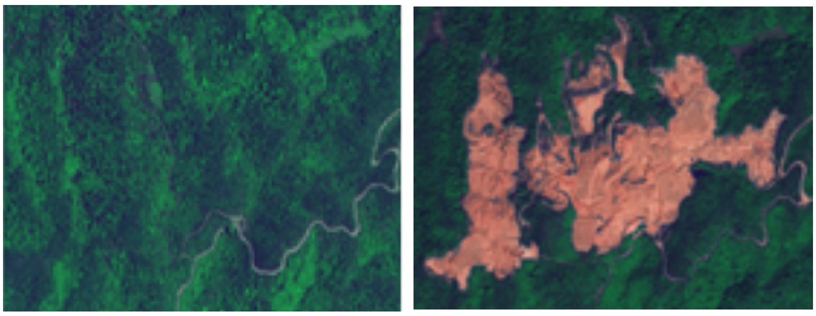

Figure 7: Comparison of the satellite photo of a rare earth mine in Ganzhou before (April 2005) and after (February 2009) pool leaching and heap leaching processes are adopted (Source: [13]).

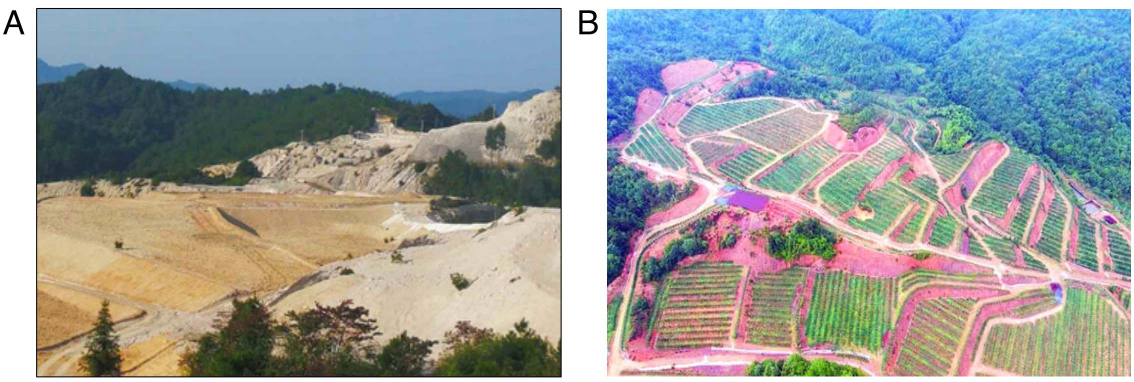


Figure 8: A) Heap leaching and a tailing site in Anyuan County, Ganzhou Prefecture. B) Bioremediation on abandoned REE mining areas in Jiangxi Province. Reproduced with permission from [12].

ponds; in one case, a potential cause may be the failure of a tailing storage dam. Additionally, the surface mining of REEs causes physical problems to the geography of the territory, including land slips, the loss of vegetation cover that results in soil erosion (Figure 8A), damage to crop production (specifically rice), and loss of biodiversity.

The impacts of REE mining in the Dingnan county and other counties in the Jiangxi Province go beyond the province's borders. The pollutants from REE mining in Jiangxi flow into the Ganjiang and Dongjiang rivers and from here into the Yangtze and Pearl rivers and other Chinese streams [10]. It is not yet clear how this impacts water quality, human and animal health and local economies beyond the mining region.

The concentration of dissolved REEs in the Ganjiang river is elevated when compared with the Chinese national average. In particular, the water concentration of europium (Eu), lanthanium (La), lutetium (Lu), samarium (Sm), terbium (Tb) and ytterbium (Yb) in REE mining areas ranged from 0.004 (Lu) to 2.412 (La) $\mu$g/L [18]. These results emphasise the need for a regional and catchment approach to the management of REE mining and associated effluents [18].

## Health impacts of REE surface mining

The impact of REEs on health has been linked to indirect atmospheric pollution from mining and associated inhalation [18, 19], as well as the presence of heavy metals in soils, which are often directly associated with REE mining [19].

Although the mining of REEs has been halted by government edict in Dingnan County, there are still some small pockets of illegal mining and the health impacts of the extraction activities still persist. Village surveys in Dingnan County show the views of respondents concerning health issues; 36.03% of respondents considered that the number of serious diseases—including various cancers–increased since the commencement of REE mining [12]. Exposure to contaminated water from surface and groundwater sources, as well as atmospheric pollution from mining dust may have been REE-mining factors related to the surge of health issues[2].

## Remediation of REE mining areas

Phytoremediation is an acknowledged approach to the remediation of mining areas [20], where vegetation is planted to extract and store heavy metals from the soil. In China the practice of phytoremediation, biochar (a charcoal-like substance derived from burning of biomass) [21] and associated remediation approaches is nationally widespread [12] and the challenges of mining and land remediation have been recognised [22].

Phytoremediation has been used in Dingnan and other counties of Jiangxi province to compensate for agricultural activities in a populated area where there is a predominance of heavy metals in the soils, common in REE mining areas. This involves planting certain species of trees, grasses and other flora. The plants used depend in part on the geochemistry of the soils which may affect the success of uptake [23, 24], for instance citrus trees have been used in Dingnan county (Figure 8B) [12]. The combined use of biochar in Dingnan county has been successful so far, however the success of these remediation operations depends on the planting of indigenous plants that are resistant to heavy metal contamination, while being suited to the local soil and climatic conditions.

## Policy Issues and conclusions

The importance of REEs for green investments and the demand and supply balance for REEs globally has raised several policy issues in countries with the highest demand: these include the security of supply and the development of alternative raw materials as well as the policy issues relating to the environmental, economic and social aspects of REE mining.

The regulation of REE and other mining varies from country to country. In Europe, guidelines for

[2]The absence of historical health records for the local incidence of different diseases makes it difficult to prove causation between REE mining and different diseases.

best practice have been produced [25], however the exploitation of REEs is still at the exploratory stage; in China, the application of environmental legislation is not always effective, because it is unclear and depends on the monitoring of mining exploitation. It is also generally recognised that pre-mining environmental impacts assessments (EIAs) are important before and during mining activities.

Measures need to be taken to lessen the EU and USA reliance on the current main source of supply in China. Alternatives to REEs are also being used and developed in a number of research institutes. These alternatives include cerium – cobalt compounds ($CeCO_3$ ) and cobalt compounds with iron germanium ($Fe_3Ge$) for use in batteries for electical vehicles. There is also research on the use of copper (Cu) as a potential replacement for REEs in rotating machines and direct drive generators in wind turbines. A further line of research is the recycling of REEs. The feasibility of alternatives will also depend on their cost effectiveness and the quality of performance in applications, as compared with the mining of widely diffused REEs, such as neodymium (Nd) and Dysprosium (Dy) [1]. Green economic development will also depend on the extent to which countries can use alternative sources to REEs for low-carbon applications.

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**Conflict of interest** The Author declares no conflict of interest.