



Summary of the collective  
scientific assessment

# **Towards a responsible use of rare earth elements throughout their life cycle**

**WHAT ARE THE PROSPECTS IN TERMS OF SUFFICIENCY,  
RECYCLING AND PRODUCTION METHODS?**





Often confused with other metals, rare earths refer to a group of 17 metals in the periodic table<sup>1</sup> of chemical elements, known as rare earth elements (REEs). They are found in a wide range of applications. Present in many of our miniaturised electronic devices, essential for medical imaging or as tools for the industrial manufacture of a wide variety of products, REEs have now become a key component of the energy transition. Offshore wind turbines and electric vehicles, for example, rely heavily on them.

These diverse uses, however, depend on a refining capacity that is 90% dominated by China, whilst the extraction of REE is limited to a handful of mines worldwide and France has no deposits that can be exploited in the short term. Faced with these challenges to sovereignty, Europe is implementing policies to secure the supply of these critical metals<sup>2</sup>. Strategically it is increasingly important to assess how a more sober use of REEs – encompassing action on demand and technological innovation – as well as recycling and alternative extraction methods (sources, methods and processes) can help reduce the vulnerability of France and Europe.

Led by the CNRS, this collective scientific assessment aims to shed light on these issues through a comprehensive review of the existing literature. A total of 4,100 scientific publications were analysed by a multidisciplinary group of 30 scientific experts to produce a synthesis and a full-length report available in open access; the main findings of this work are summarised here.

#### Key data (see report)

- Global primary REEs resources<sup>3</sup> are estimated at 478 million tonnes (Mt)
- In 2024, 70% of extraction and 90% of refining take place in China, which holds 35% of the world's resources, ahead of five countries each holding 9–11%, all of which are located outside Europe
- In 2024, global mining production reached 390 kilotons (kt) (USGS)
- Global production of REEs has been growing by an average of 13% per year since 2015 (doubling every six years)
- One-third of global REEs consumption is used in the manufacture of permanent magnets
- One offshore wind turbine motor contains as many REEs as 2 million mobile phones
- Less than 1% of REEs are recycled globally
- The quantity of REEs present in coal ash and bauxite residues generated worldwide in 2020 was 320 kt and 150 kt respectively

## WHAT CHALLENGES DOES FRANCE AND EUROPE FACE?

### What are REEs and what are they used for?

REEs do not all exhibit the same natural abundance or the same properties<sup>3</sup>, although they are always found together in ores and co-extracted. These differences have a **direct impact on their price and criticality**<sup>2</sup>. By 2025, for instance, the REEs used to manufacture catalysts for the petrochemical industry (lanthanum, cerium) are worth 100 to 1,000 times less than those used for high-performance permanent magnets (dysprosium, terbium). **The prices of REEs fluctuate with great volatility** depending on their natural abundance, their purity (depending on intended usage), their uses and the global geopolitical context.

REEs are used across a wide range of industrial sectors (transport, healthcare, digital technology, etc.), some of which, such as energy and defence, being strategic. **A third of their consumption relates to the manufacture of permanent magnets**<sup>5</sup>, which are **key components in offshore wind turbine motors and electric vehicles**, helping to improve their efficiency. REE magnets are also found in drone motors, hard drives, mobile telephone speakers and even in vacuum cleaners. REEs are also used in the manufacture of optical fibres and certain metal alloys for the aerospace industry, in lasers, catalytic converters and as contrast agents for MRI scans. Finally, REEs also possess strictly industrial uses, such as catalysis in the petrochemical industry or as polishing powders for precision optics in particular (lenses, screens, windscreens, etc.).

**The quantities used in the production of different materials vary greatly depending on the technology:** from 0.01% by mass for an optical fibre to nearly 30% for a marine wind turbine magnet.

### Who produces them and what are the geopolitical implications?

Many countries possess REE resources<sup>3</sup>, but the concentration in the ores is often too low for extraction to be economically viable. A distinction must also be made between ore extraction capacity, on the one hand, and refining and processing capacity on the other. Around ten countries have exploitable reserves<sup>5</sup> including Sweden. In the 2000s, China accounted for almost all global ore extraction (up to 97%). **China's export embargo** in 2010 marked a geopolitical turning point, **prompting several countries to develop or restart REE extraction**. By 2024, the United States and Myanmar accounted for 11% and 7% of global ore extraction, respectively, while China accounted for 70% of ore extraction. However, still 90% of the REEs mined worldwide are refined in China. For the past 25 years, **China has therefore pursued a policy of controlling the entire value chain:** ore mining, separation and refining of REEs, processing into intermediate products (materials) and integration into finished products (devices).

### What are the impacts of their extraction?

The overall environmental impact of REE extraction process is greater than that of other metals. Associated with **radioactive** elements in the subsurface, REEs require numerous separation steps that are highly demanding in terms of water and chemical consumption. These processes and the waste they generate pose a **proven risk to the environment**, primarily around heavily contaminated areas (extraction or processing sites). As a result, extraction and processing activities and their associated health risks generate significant local **social tensions**.

## ARE THERE WAYS TO REDUCE THE USE OF REEs?

Ways to reduce the consumption of REEs include replacing them with less critical elements in materials, improving the efficiency of devices requiring their usage, and pursuing a sufficiency-oriented approach to resource use.

### Can REEs be substituted or reduced in materials?

**In the case of permanent magnets, there are methods for reducing the amount of certain REEs by adjusting the composition and structure of the magnets, or their placement within devices.** For NdFeB permanent magnets, the amount of dysprosium can be halved without any loss of magnetic performance. Neodymium can also be partially substituted with less critical REEs, though in this case its reduction also lessens the magnetic performance of the final product. Completely eliminating REEs would require increasing the magnet mass by a factor of 4 to 5 to maintain an equivalent performance. This is feasible for certain uses (in electric vehicles, for example), but very difficult for others (offshore wind turbines). Finally, one approach to reducing REEs involves optimising the arrangement of permanent magnets within the motor, or combining them with REE-free magnets or magnet-free technologies. For permanent magnets in electronic equipment, the shift towards miniaturisation renders their replacement with REE-free magnets complex. **Thus, in magnets, REEs can be substituted in certain uses, but this replacement often compromises device performance and weight.**

Nickel-based batteries containing REEs are gradually being replaced by lithium-ion batteries that are REE-free but rich in cobalt, nickel and manganese, shifting demand towards other critical metals. The replacement of phosphor lamps with white LED technology has reduced the amount of REEs by two orders of magnitude, whilst maintaining the same performance. **In these cases, it is technological breakthrough rather than material optimisation that have enabled REE reduction.**

For so-called 'dispersed' uses, small quantities of REEs are sufficient to enhance the performance of many other materials (0.01—0.1% in optical fibre, for example). In this

case, the literature demonstrates that there is generally no viable substitute for achieving equivalent performance. **For dispersed uses, REE consumption is often very low, but allows for a significant functional gain.**

## What is the applicable legal framework, and what role may sufficiency in use play?

Although REEs have been classified as critical raw materials subject to regulation in Europe since 2024, **products containing them (such as electronic waste) are not covered by any specific legal framework.** The European Critical Raw Materials Act (2024) aims to secure their supply by 2030 by promoting the relocation of production and the diversification of sources, encouraging recycling and advocating for a circular economy approach to resource management. The literature highlights criticism of this Act, which focuses much more on supply than on demand. The concept of sufficiency (or sobriety) in use, meanwhile, features in the French and European legislation pertaining to a circular economy model. The traceability requirements (digital passport, environmental performance declaration) set out in the Ecodesign for Sustainable Products European Regulation (2024) are presented in the literature as a crucial means **of ensuring transparency and democratising value chains. Ultimately, European law seeks to reconcile security of supply with sufficiency in use.**

Several of the seven pillars of the circular economy model can indeed influence demand for REEs. The functional economy, which prioritises use through sharing rather than individual ownership, promotes sufficiency by optimising usage intensity (as in the case of electric vehicle leasing). Its economic impact and drivers of acceptance, in relation to products containing REEs, however, remain poorly studied, reflecting an overall lack of visibility for these metals. This **lack of visibility is a barrier to resource efficiency.** Eco-design, in turn, facilitates reuse, repair and recycling. **A key question remains for a reasonable European demand for REEs: how to ensure that the performance level of objects matches their intended use ?**

## WHAT ARE THE DRIVERS AND BARRIERS TO RECYCLING?

### What are the available recycling technologies?

The global recycling rate for REEs has remained at 1% since 2010. Life-cycle and material flow analyses, however, demonstrate that **REE recycling processes have a smaller carbon footprint than primary extraction.** Innovative pre-treatment and metallurgical technologies (hydrometallurgy, bioprocesses, etc.) or the development of short recycling loops

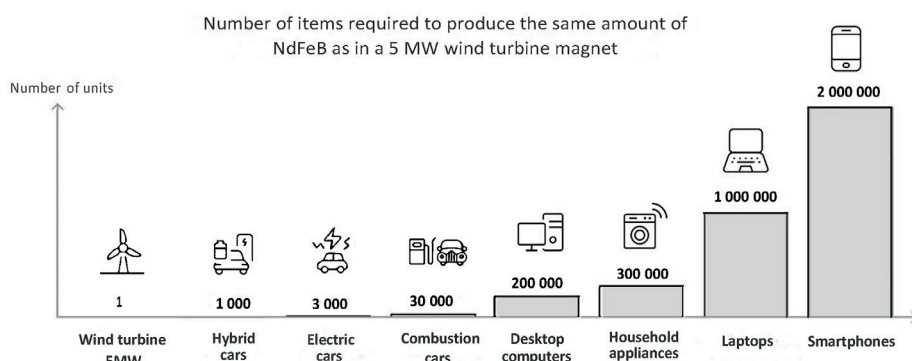
(from magnet to magnet, for example) also significantly reduce environmental impact and achieve high recovery rates; though these practices require further development before industrial implementation is possible. **Technical feasibility has been demonstrated, the potential for recycling is significant, and end-of-life waste is a credible secondary resource for creating a responsible ‘urban mine’.**

### What factors influence widespread REEs recycling

Literature in the social sciences — economics, sociology, geography, and management — reveal that a range of factors influence investment in technology and the development of recycling in France and Europe. The potential for recyclability **depends on whether REEs are concentrated or dispersed** (i.e. the proportion of REEs in materials and the number of collectable items). A single offshore wind turbine contains the equivalent amount of REEs as would be found in 2 million mobile phones (which represents a dispersed use, i.e. a very large number of devices and few REEs per device). **The collection of dispersed REEs poses a logistical as well as economic challenge.** More concentrated sources (magnets from wind turbines and electric vehicle motors) represent strategic potential for the circularity of REEs. **The lifespan of these devices,** however, can conversely affect the renewal of the stock: REEs from a wind turbine remain unavailable for several decades. Finally, this activity is subject to **the extreme volatility of the REEs market** and to prices that vary greatly from one REE to another.

### What are the legal and policy frameworks for recycling REEs?

Circular economy and waste management legislation applies to the recycling of products containing REEs. Several directives — notably those regarding electronic waste and batteries — encourage the recovery and reuse of materials. There is, however, no legislation requiring the presence of REEs in products to be disclosed, nor does the legislation specify actions to be taken regarding recycling. **This lack of focus on REEs hinders their identification for collection and sorting.** For example, European legislation mandates the recycling of 85% of a



vehicle's mass without specifying the composition, thereby favouring the recycling of heavy materials such as steel. The existing legal framework and policy incentives are therefore not yet adapted to the recycling of REEs. **At national and regional levels, effective policies for exploiting the urban mine rely on a balance between regulation, economic incentives and innovation. Above all, the success of the urban mine depends on collaboration between a wide range of actors throughout the chain.**

Against the backdrop of a rapidly growing global demand for REEs, however, the urban mine's historical stock remains insufficient. While it may **meet certain demands and minimise imbalances for some particularly critical REEs**, other sources of supply must be considered.

## WHAT OPPORTUNITIES FOR ALTERNATIVE EXTRACTION METHODS EXIST?

### What are the available substitutes for REEs sources?

France has the world's second-largest maritime zone. **Offshore mineral resources** could provide a source of REEs, but quantifying them is difficult and **significant uncertainties subsist** (for example, polymetallic nodules worldwide are estimated to contain between 2 and 12 Mt of REEs, and the total sediment volume is in the hundreds of Mt). Similarly, the economic viability and technical feasibility of extraction also remain uncertain. Above all, **the scale of the potential damage** would be such that it is impossible to know whether the seabed, which plays a key role in carbon storage, could return to equilibrium after exploitation. Whilst France supports a ban on exploitation in international waters, its national legislation does not prohibit it; meanwhile, the European Parliament has already come out in favour of such a ban, whereas the national legislation of EU Member States has not yet done so.

There also exists well-identified primary potential in magmatic rocks in **Northern Europe, in Sweden (Kiruna) and Norway. Greenland has eight** large, unexploited REE deposits (totalling 34.79 Mt). Finally, **as Brazil possesses the second largest stock of primary resources, this may suggest the presence of REEs in nearby French Guiana.**

**Mining and industrial wastes are estimated to represent a significant potential source of REEs in France and Europe.** Although less concentrated in REEs than primary deposits, these wastes are attracting growing interest due to the important volumes generated each year. They have also already undergone the most energy-intensive processes (crushing, grinding), which places them firmly within resource recovery and circularity initiatives: for example, the concentration of REEs in bauxite mining residues is twice that found in the ore prior to alumina extraction; the coal ash (a by-product of power stations) generated worldwide each year contains a quantity of

REEs of the same order of magnitude as that extracted from primary sources. The available data pertaining to their exact quantities and properties, however, remains limited.

### What are innovative and more eco-friendly extraction processes?

Reducing the environmental impact of REE extraction relies on integrated 'resource—process—environment' optimisation, based on the mineralogy of the deposit, circular hydrometallurgy and the internal recycling of reagents. Integrated optimisation aims to reconcile security of supply with sustainability requirements. As with recycling, unconventional approaches to the extraction of mining waste (solvo-, iono- or bio-metallurgy) reveal prospects for more sustainable pathways. Finally, the literature highlights **zero-waste approaches** that recover all mining residues (iron, titanium, etc.), with REEs being particularly relevant for limiting the **environmental impacts associated with the storage of these residues.**

### How can we better consider the social and environmental consequences of mining?

As the rules governing the extraction of REEs are the same as those for other metals (REEs are often co-extracted alongside other metals), the literature reviewed included relevant case studies (for Europe and beyond) highlighting the social and political dimensions of mining. Whilst the corporate social and environmental responsibility of mining companies is often still deemed insufficient, European law is moving towards stricter regulation with **corporate sustainability due diligence** requirements. These directly impose enhanced obligations on companies throughout the value chain, including in countries outside of Europe. The literature review also demonstrates that **social protests**, as a reaction to these projects, are directly correlated to the existence of **prior, sincere and open debate on the very appropriateness of developing new mines**, i.e. mines for what purpose and whose benefit? These protests are not resolved through mere educational or compensatory measures aimed at the affected local populations. Furthermore, concerns regarding environmental justice in the critical metals industry are not limited to local impacts, but extend well beyond national borders. **Securing the supply of REEs to attain European sovereignty without a democratic debate regarding which uses should be encouraged, reduced or abandoned is difficult to envision.**

- 1-** REEs are not rare. They are abundant, but occur in low concentrations in the Earth's crust. They comprise 17 elements: 15 lanthanides (lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium), yttrium and scandium, although the latter is excluded from the assessment.
- 2-** A **critical** raw material plays an important economic role, is difficult to substitute in economic activity, and is subject to high supply risks.
- 3-** **Resources** refer to REEs contained in underground ores (primary resources) or in urban, mining or industrial waste (secondary resources). **Reserves** refer to resources that can be economically exploited.
- 4-** Different REEs possess distinct physico-chemical properties — catalytic, magnetic, optical — that make them unique.
- 5-** Permanent magnets produce a permanent magnetic field without an external energy supply. In an electric vehicle, a rotating magnetic field generated by an electric current drives the magnets, which in turn drive the vehicle via a mechanical transmission. Conversely, during braking, the rotation of the magnets driven by the vehicle induces an electric current that recharges the battery.

## IN BRIEF

**Given France's and Europe's dependence on REEs, the assessment analyses the drivers and limitations :**

- **A reduction in the use of REEs is feasible through technology and reduced consumption**, the latter of which has yet to be thoroughly and scientifically studied. Beyond a single scientific analysis, reduced consumption demands consideration of usage priorities, which requires clarifying what constitutes essential use.
- France and Europe possesses **significant secondary resources** :
  - Waste from consumer products: the **urban mine** (magnets from electric car motors, electronic waste, etc.)—which can be mobilised through recycling.
  - **Mining and industrial** waste (coal ash, power station by-products; bauxite residues from alumina extraction).
- Successful recycling relies on an organised **collection system, infrastructure and a stable economy** (incentives, subsidies to limit the effects of volatility in REE prices, etc.).
- Controversies surrounding mining often arise from **a lack of prior and sincere debate regarding environmental impact, project purpose and shared benefits with local communities.**

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