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# How to search for patents on the recovery of rare earth metals from electronic waste

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## Abstract

Waste and electrical and electronic equipment (WEEE), generally disposed of in landfills, contains precious elements, called rare earth metals, which are applicable in many industrial sectors.

Only 1% of the rare earth elements are recycled from the residues as mentioned above.

This study aims to verify the technological trend, through the patent analysis, of the methods for recovering rare earth metals from end-of-life electronic equipment.

The patented methods were searched on the Orbit Intelligence database, using a combination of keywords and classification codes (IPC and CPC).

Japan is, in fact, the first country for several patents in this sector. However, the filing trend of patent applications has been decreasing since 2018.

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## Introduction

Rare earth elements (REE - Rare Earth Elements) are a group of metals that include 17 elements, namely yttrium, scandium, and 15 lanthanides. These elements are generally divided into two categories, based on their electronic configuration: heavy (europium, gadolinium, terbium, dysprosium, holmium, erbium, thallium, ytterbium, lutetium, and yttrium) and light rare earth metals (lanthanum, cerium, praseodymium, neodymium, promethium, and samarium).

Five are the most critical elements regarding supply and industrial use: neodymium, dysprosium for permanent magnets), europium, terbium, and yttrium (superconductors and lasers).

20% of rare earth is used in catalysts (Ce, La), 21% in magnets (Sm, Nd, Dy), 18% in alloys, 12% for producing powders, and 7% as phosphors.

Currently, global rare earth production is dominated by China (85%), followed by Australia (10%), Russia (2%), India (1%), Brazil (1%), Malaysia, and Vietnam. All other countries must import these items. [1]

It would therefore be desirable to intensify the methods and processes for the recovery of rare earth metals from end-of-life products/devices, also in consideration of the significant increase in the amount of electronic waste (WEEE), which will reach 52.2 million tons in 2021. [2]

Only 1% of rare earth elements is recycled from final products, such as permanent magnets, fluorescent lamps, Ni-MH batteries, and catalysts.

There are three types of recovery adopted, starting from production residues (for example during the manufacture of NdFeB magnets), from devices deriving from the urban separate collection (computers, telephones, ...), or industrial waste.

Most of the rare earth recycling activity currently derives from permanent magnets, in particular from those present in electronic waste, using hydrometallurgical, and pyrometallurgical techniques [3] or by gas phase extraction. [4]

Electronic waste is defined as all those devices (and their components) that have a plug, a cable, or a battery and have reached the end of their life. These residues can be classified as heat exchange equipment (air conditioners, refrigerators, stoves, and electric fans), small (calculators, video cameras, electric razors, coffee machines, etc.), or large devices (washing machines, dishwashers, photocopiers, photovoltaic panels), fluorescent lamps, screens (TVs, monitors, laptops, or tablets) and communication devices (telephones and navigators).

Rare earth metals are present above all in the latter two product categories (a smartphone contains less than a gram) and can be recycled using, for example, an oxidation-reduction protocol for the recovery of neodymium, praseodymium, and dysprosium from permanent magnets. [5][6]

What is the technological trend of methods for the recovery of rare earth?

From a search of the publications on the Scopus database, the trend has been growing since 2014, with a peak in 2018 (see Figure 1), with a total of 312 papers.

To find the scientific articles, the following search string on Scopus was used: (((TITLE-ABS-KEY (rare AND earth AND metals)) AND (recovery)) OR (TITLE-ABS-KEY (rare AND earth AND metals AND recovery)) OR (TITLE-ABS-KEY (rare AND earth AND elements AND recovery)) OR (TITLE-ABS-KEY (REE AND recovery))) AND (TITLE-ABS-KEY (e-waste OR "electronic waste " OR "electric and electronic waste" OR WEEE))

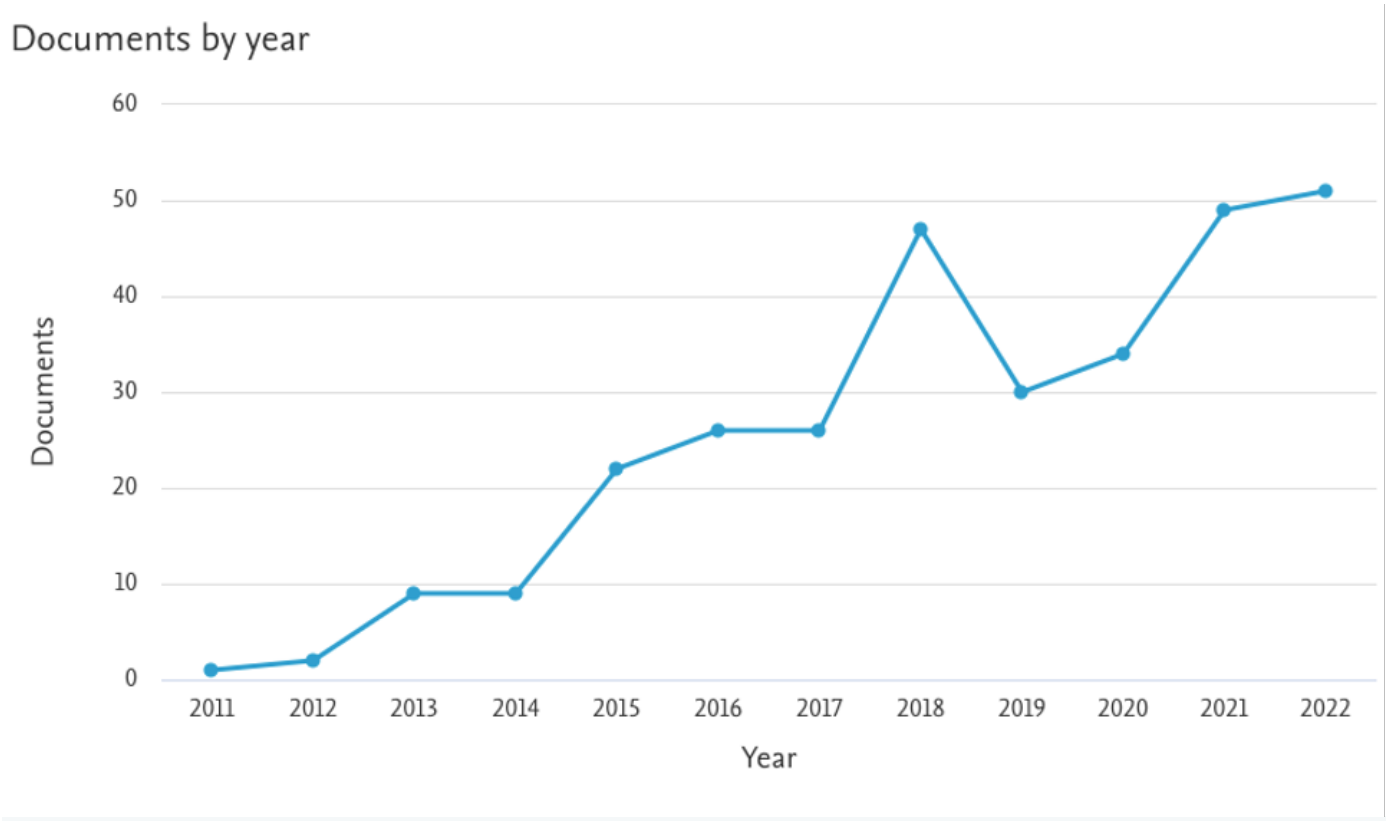



**Figure 1.** Number of scientific publications per year (Source: Scopus; accessed 22 February 2023)

To have a complete overview of the technological evolution of the sector, it is necessary to carry out research complementary to scientific publications, i.e., patent research. The following paragraph describes the methodology used to plan a search for patent information.

## Methodology

The patent analysis on methods for recovery of rare earth metals from WEEE was carried out on the Espacenet (https://worldwide.espacenet.com) and Orbit Intelligence patent databases (https://www.orbit.com) using a combination of keywords and IPC and CPC classification codes

The preparation and treatment (separation and purification) of rare earth metals are classified in the main groupC01F 17/00 and in subgroups up to C01F 17/38.

Version 1 of the IPC scheme did not include subgroups, which were introduced in version 2020.01. There are no differences in the titles of the IPC and CPC codes, except in the number of documents categorized in the two classification schemes.

Searching using only the C01F 17/00 classification and/or compound names may be a limiting procedure.

It is necessary to verify that there are no other relevant codes, which could make the prior art search more complete. Using Espacenet as a reference database and some simple search queries (see Table 1), a series of classification codes listed in Table 2 were obtained and then used in the subsequent research on Orbit.

**Table 1.** List of search queries used on Espacenet to find other classification codes.

| Query No. # | Results No. # | Search query |
|---|---|---|
| **1** | 141 | ctxt = "rare earth" AND (ftxt = "recover*" OR ftxt = "recuperar*" OR ftxt = "recycl*" OR ftxt = "extract*") AND (ftxt any "WEEE" OR ftxt any "smartphone") |
| **2** | 6 | (ftxt = "recover*" OR ftxt = "recuperar*" OR ftxt = "recycl*" OR ftxt = "extract*") AND (ftxt any "WEEE" OR ftxt any "smartphone") AND cl any "C01F17" |

**Table 2.** List of classification codes (IPC/CPC) resulting from Espacenet search.

| Classification code | Definition |
|---|---|
| **C22B 59/00** | Obtaining rare earth metals (IPC/CPC) |
| **H01F 1/053+** | Alloys containing rare earth metals (IPC/CPC) |
| **H01F 1/15325** | Amorphous metallic alloys containing rare earth (CPC) |
| **Y02P 10/20** | Recycling (CPC) |
| **Y02W 30/50** | Reuse, recycling, or recovery technologies (CPC) |
| **Y02W 30/82** | Recycling of waste of electrical or electronic equipment [WEEE] (CPC) |
| **B09B 2101/15** | Electronic waste (CPC) |
| **B09B 2101/15** | Electronic waste (IPC) |

The IPC code C22B 59/00 has also been present since IPC version 1; what changes is the title (in version one it is "METALS OF THE RARE EARTHS" while in version 2 and in the following ones it is renamed to "OBTAINING RARE EARTH METALS").

The IPC/CPC indexing schemes (B09B 2101/15) used to classify the various types of electronic waste are relatively recent [IPC: 2022.01]. They include three subgroups: B09B 2101/16 (batteries), B09B 2101/17 (printed circuits), and B09B 2101/18 (smartphones and tablets).

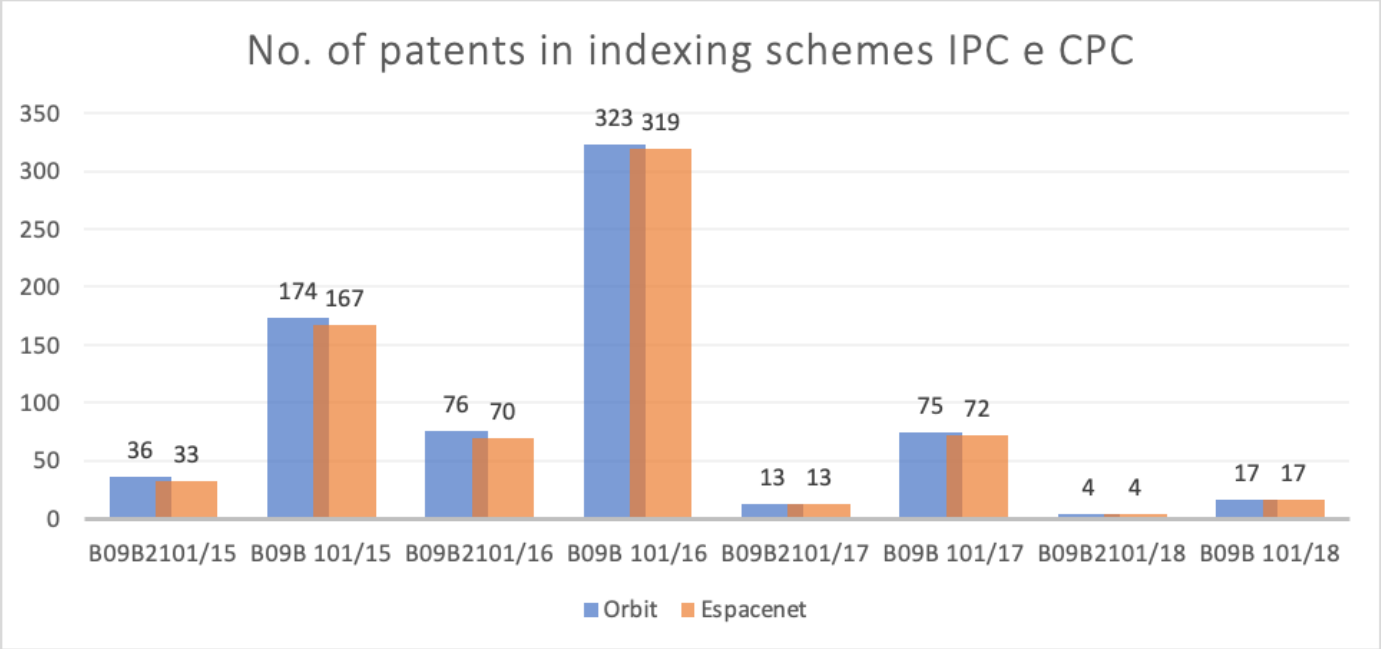
Although the number of documents present in these two schemes is different (see Graph 1), this factor did not affect the final result of the research.

The IPC code H01F 1/053 has undergone a revision since version 5 of the IPC scheme [in the previous one (1985.01)], where the reference code was H01F 1/04 - and generically defined as "metals or magnetic alloys").

No significant results are obtained using the above code on Espacenet (see Table 3).

Table 3. Search queries used on Espacenet to find classification codes.

| Query No. # | Results No. # | Search query |
|---|---|---|
| 1 | 0 | (ftxt = "recover*" OR ftxt = "recuperar*" OR ftxt = "recycl*" OR ftxt = "extract*") AND ctxt any "rare earth" AND ipc any "H01F1/04" AND (ftxt any "smartphone" OR ftxt any "tablet" OR ftxt any "laptop") |
| 2 | 6 | (ftxt = "recover*" OR ftxt = "recuperar*" OR ftxt = "recycl*" OR ftxt = "extract*") AND ftxt any "rare earth" AND ipc any "H01F1/04" AND (ftxt any "mobile phone" OR ftxt any "tablet") |




**Graph 1.** No. of patent documents in indexing schemes B09B 20101/15 – 18

The main concepts to be combined in the patent search are illustrated in Figure 3.

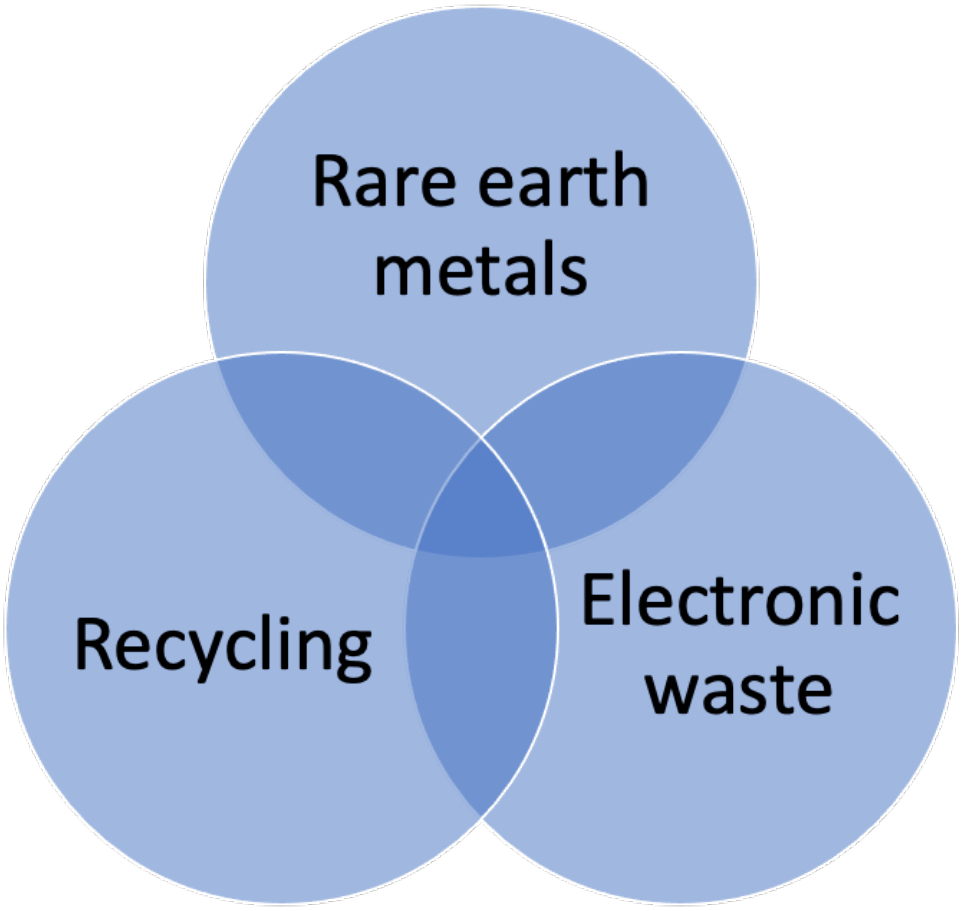



**Figure 3.** Concepts to be combined in prior art searches.

## Results

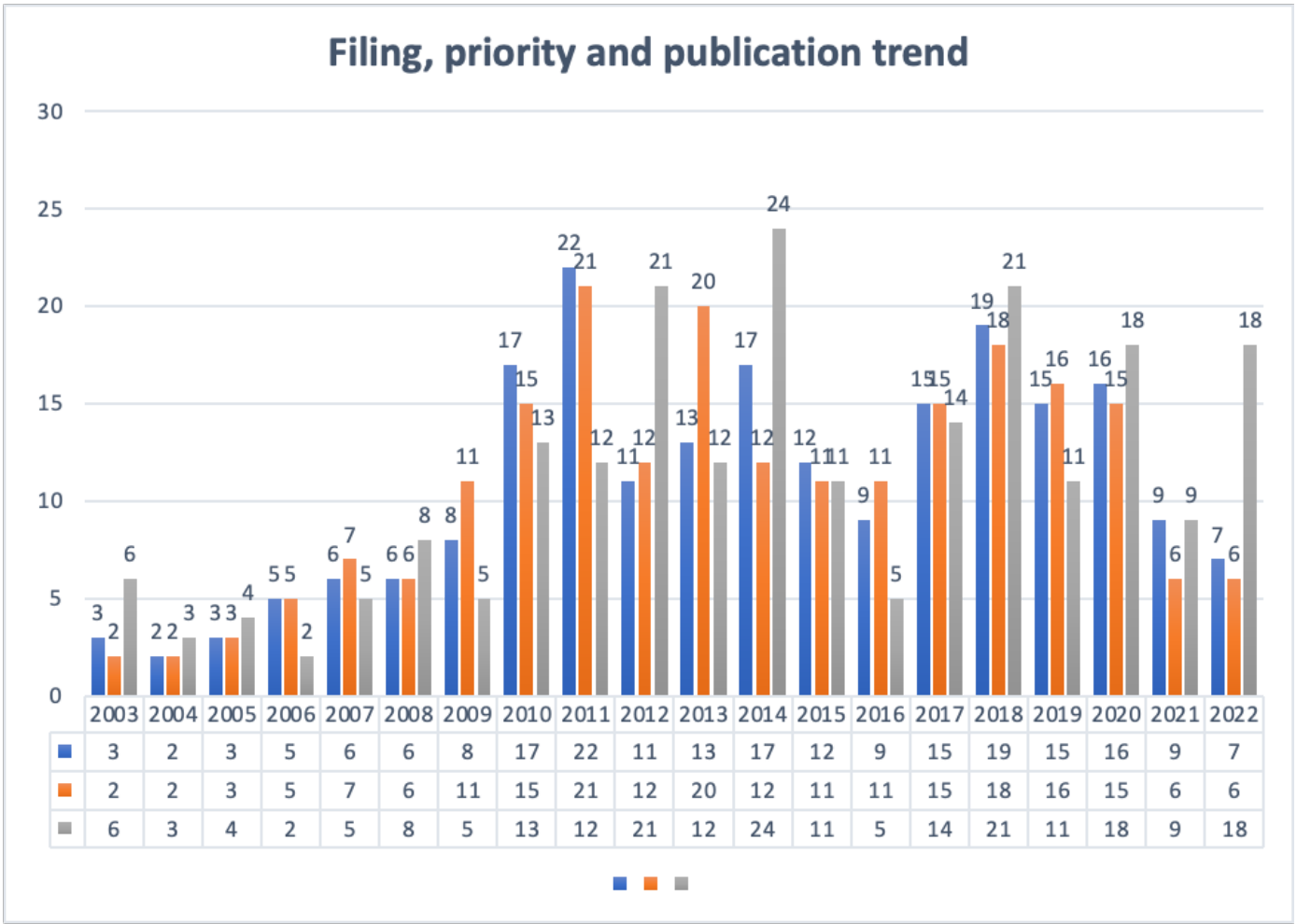
The search strings used to retrieve the patent data are summarized in Table 4.

**Table 4.** List of search queries used on the Orbit database.

| Query No. # | Results No. # | Search query |
|---|---|---|
| 1 | 124764 | (Y02P-010/20 OR Y02W-030/50 OR Y02W-030/82)/CPC |
| 2 | 4164179 | ((WEEE OR "E_WASTE" OR "WASTE ELECTRICAL ELECTRONIC EQUIPMENT" OR "ELECTRONIC WASTE" OR TABLET OR LAPTOP OR "MOBILE PHONE" OR SMARTPHONE OR "MOBILE DEVICE" OR TELEPHONE OR "ELECTRONIC DEVICE")/TI/AB/CLMS/DESC/ODES/ICLM OR (B09B-2101/15 OR B09B-2101/16 OR B09B-2101/17 OR B09B-2101/18)/CPC) |
| 3 | 396385 | ((RARE 1D EARTH)/TI/AB/CLMS/DESC/ODES/ICLM OR (C01F-017+ OR C22B-059/00 OR H01F-001/53+ OR H01F-01/15325)/IPC/CPC ) |
| 4 | 116 | 1 AND 2 AND 3 |
| 5 | 158 | ((RARE 1D EARTH))/TI/AB/CLMS/DESC/ODES/ICLM AND (Y02W-030/82)/CPC |
| 6 | 7 | ( (RECOVER+ OR RECYCL+ OR RECUPERAT+)/TI/AB/CLMS/DESC/ODES/ICLM AND ((RARE 1D EARTH))/TI/AB/CLMS/DESC/ODES/ICLM ) AND (B09B-2101/15 OR B09B-2101/16 OR B09B-2101/17 OR B09B-2101/18)/CPC |
| 7 | 265 | 4 OR 5 OR 6 |
| 8 | 4164179 | ((WEEE OR "E_WASTE" OR "WASTE ELECTRICAL ELECTRONIC EQUIPMENT" OR "ELECTRONIC WASTE" OR TABLET OR LAPTOP OR "MOBILE PHONE" OR SMARTPHONE OR "MOBILE DEVICE" OR TELEPHONE OR "ELECTRONIC DEVICE")/TI/AB/CLMS/DESC/ODES/ICLM OR (B09B-2101/15 OR B09B-2101/16 OR B09B-2101/17 OR B09B-2101/18)/CPC) OR (B01B-101/15 OR B01B-101/16 OR B01B-101/17 OR B01B-101/18)/IPC |
| 9 | 7 | ((RECOVER+ OR RECYCL+ OR RECUPERAT+ OR EXTRACT+)/TI/AB/CLMS/DESC/ODES/ICLM AND ((RARE 1D EARTH))/TI/AB/CLMS/DESC/ODES/ICLM ) AND ((B09B-2101/15 OR B09B-2101/16 OR B09B-2101/17 OR B09B-2101/18)/CPC OR (B01B-101/15 OR B01B-101/16 OR B01B-101/17 OR B01B-101/18)/IPC) |

The patent search provided a total of 265 results (35.8% is the percentage of granted patents); only 134 are active patents (95 granted).

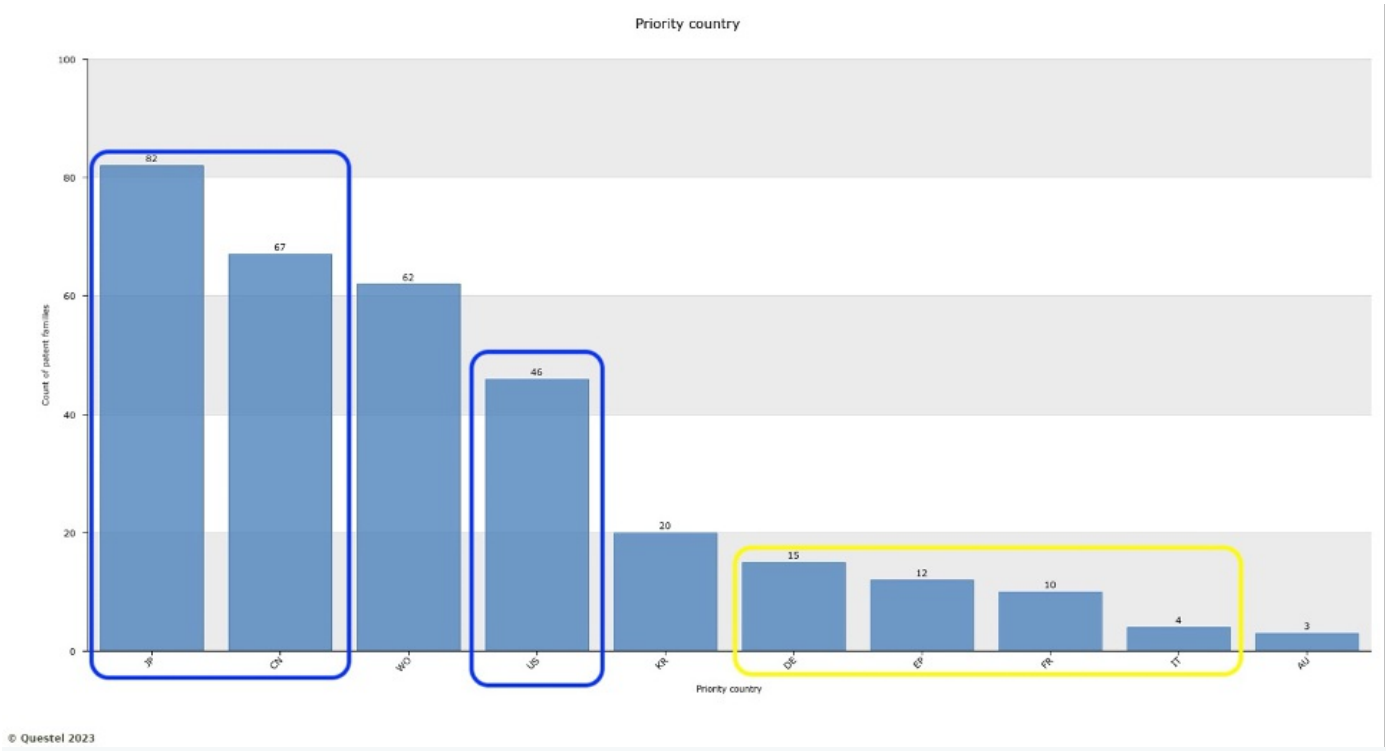
The number of filings of patent applications per year has been decreasing since 2018 (see Graph 2).



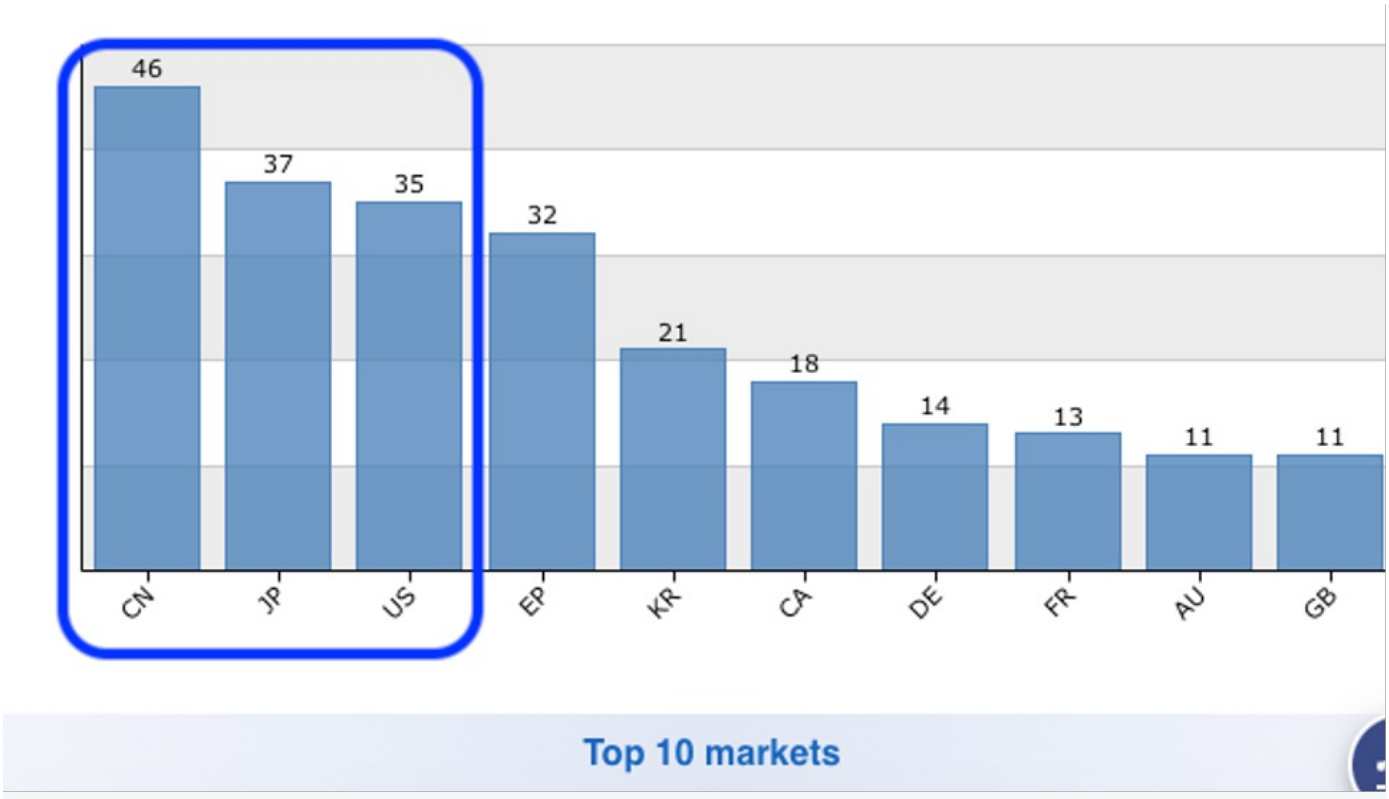

| | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ■ | 3 | 2 | 3 | 5 | 6 | 6 | 8 | 17 | 22 | 11 | 13 | 17 | 12 | 9 | 15 | 19 | 15 | 16 | 9 | 7 |
| ■ | 2 | 2 | 3 | 5 | 7 | 6 | 11 | 15 | 21 | 12 | 20 | 12 | 11 | 11 | 15 | 18 | 16 | 15 | 6 | 6 |
| ■ | 6 | 3 | 4 | 2 | 5 | 8 | 5 | 13 | 12 | 21 | 12 | 24 | 11 | 5 | 14 | 21 | 11 | 18 | 9 | 18 |

**Graph 2.** Trend of filing, priority, and publication of patent applications (Orbit data; own calculations).

Japan has the highest number of priority patent application filings (Chart 3), followed by China and the United States. As far as publications are concerned, China is the first country to the number of patents (see Graph 4).



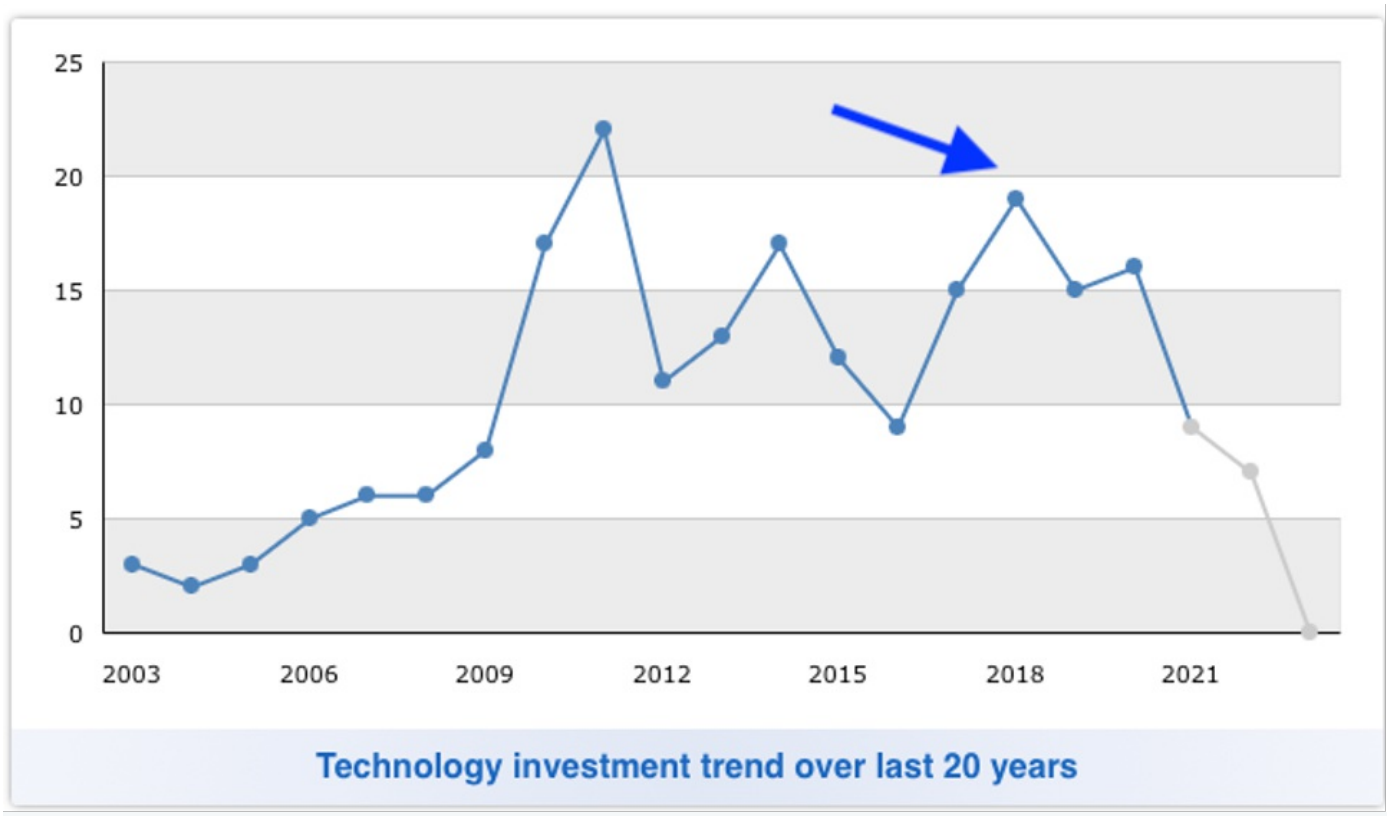

**Graph 3.** List of countries by number of priority applications (Orbit data; own calculations)




**Graph 4.** Top 10 countries per number of published patents.

## Concluding remarks

China is currently the most important country for mining and exporting rare earth metals. Other nations, such as Japan and the United States, [1] must find alternative supply routes to not depend totally on China. One solution is the recovery of these elements from electronic waste. Japan is, in fact, the first country for several patents in this sector (see Graph 3). However, the filing trend of patent applications has been decreasing since 2018 (see Graph 5).




**Graph 5.** Number of filings by priority date.

## References


1. [a, b] *X. Du, T.E. Graedel, Uncovering the end uses of the rare earth elements, Science of the Total Environment (2013), 461 – 462, 781 - 784 https://doi.org/10.1016/j.scitotenv.2013.02.099*
2. [^] *S. Dev et al., Mechanisms of biological recovery of rare-earth elements from industrial and electronic wastes: A review, Chemical Engineering Journal (2020), 397, 124596 https://doi.org/10.1016/j.cej.2020.124596*
3. [^] *N. Swain, S. Mishra, A review on the recovery and separation of rare earths and transition metals from secondary sources, Journal of Cleaner Production (2019), 220, 884 – 898 https://doi.org/10.1016/j.jclepro.2019.02.094*
4. [^] *S.M. Jowit et al., Recycling of the rare earth elements, Current Opinion in Green and Sustainable Chemistry (2018), 13:1-7 https://doi.org/10.1016/j.cogsc.2018.02.008*
5. [^] *D. Rodríguez-Padrón et al., Recycling electronic waste: Prospects in green catalysts design, Current Opinion in Green and Sustainable Chemistry (2020), 25:100357 https://doi.org/10.1016/j.cogsc.2020.100357*
6. [^] *V. Sahajwalla, R. Hossain, The science of microrecycling: a review of selective synthesis of materials from electronic waste, Materials Today Sustainability (2020), 9, 100040 https://doi.org/10.1016/j.mtsust.2020.100040*