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Report on Critical Raw Materials and the Circular Economy

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1. INTRODUCTION

This report has been produced under the Action Plan on Circular Economy (see Section 1.2.1) in which the Commission set out to issue a report on critical raw materials and the circular economy in 2017, in order to ensure a coherent and effective approach, provide key data sources, promote best practices and identify possible further actions.

The report should be seen in the context of the political priorities of the Commission – especially relevant are the priorities on jobs, growth and investment, Energy Union and climate, the internal market, trade policy and global efforts on sustainable development.

More specifically, it supports implementation of the renewed EU Industrial Policy Strategy[1] presented by President Juncker in his State of the Union Address 2017. The renewed strategy highlights the importance of adapting to changes brought on by the transition to a low-carbon and more circular economy, as well as the strategic importance of raw materials for the EU manufacturing industry.

This report is based on a recently published JRC report[2], especially for the sectorial analysis presented in Section 5.

1.1. Critical raw materials

1.1.1. Background and definition

Raw materials are essential for the production of a broad range of goods and applications used in everyday life. They are intrinsically linked to **all industries across all supply chain stages**. They are crucial for a strong European industrial base, an essential building block of the EU's growth and competitiveness. The accelerating technological innovation cycles and the rapid growth of emerging economies have led to a steadily increasing demand for these highly sought after metals and minerals. The future global resource use could double between 2010 and 2030[3].

To address the growing concern of securing valuable raw materials for the EU economy, the Commission launched the European Raw Materials Initiative in 2008. It is an integrated strategy that establishes targeted measures to secure and improve access to raw materials for the EU. One of the priority actions of the Initiative was to establish a list of Critical Raw Materials (CRMs) at the EU level.

The fact that the most recent list of critical raw materials for the EU was adopted together with the renewed EU Industrial Policy Strategy on 13 September 2017 reflects the high importance that the Commission continues to attach to the list. The Commission is also engaged in a dialogue on critical raw materials with the US and Japan - the seventh annual meeting and conference took place in Pittsburgh on 12 October 2017.

CRMs are particularly important for **high tech products and emerging innovations** - technological progress and quality of life are reliant on access to a growing number of raw materials. For example, a smartphone might contain up to 50 different metals, all of which giving different properties such as light weight and user-friendly small size. CRMs are irreplaceable in solar panels, wind turbines, electric vehicles, and energy efficient lighting and are therefore also very relevant for fighting climate change and for improving the environment.[4] For example, the production of low-carbon technologies –

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[1] Communication "Investing in a smart, innovative and sustainable industry", COM(2017) 479

[2] Critical Raw Materials and the Circular Economy. Background report. JRC Science-for-Policy Report. December 2017, EUR 28832 EN, http://dx.doi.org/10.2760/378123, JRC108710.

[3] Decoupling natural resource use and environmental impacts from economic growth. A Report of the Working Group on Decoupling to the International Resource Panel. UNEP.

[4] https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

necessary for the EU to meet its climate and energy objectives – is expected to increase the demand for certain raw materials by a factor of 20 by 2030[5].

The list of Critical Raw Materials contains raw materials which reach or exceed thresholds for both **economic importance** and **supply risk**.[6] The Commission established the first list in 2011 and committed to update it at least every three years to reflect market, production and technological developments.[7] The first assessment, conducted in 2011, identified 14 CRMs out of the 41 non-energy, non-agricultural raw materials assessed. In the 2014 exercise, 20 raw materials were identified as critical out of the 54 materials assessed.[8]

In the 2017 exercise, **27 CRMs** were identified using a revised methodology for an assessment of 61 raw materials (comprising 58 individual and 3 grouped materials, altogether 78 individual materials). [9]

Critical Raw Materials			
Antimony	Fluorspar	LREEs	Phosphorus
Baryte	Gallium	Magnesium	Scandium
Beryllium	Germanium	Natural graphite	Silicon metal
Bismuth	Hafnium	Natural rubber	Tantalum
Borate	Helium	Niobium	Tungsten
Cobalt	HREEs	PGMs	Vanadium
Coking coal	Indium	Phosphate rock	

Table 1: The 2017 List of Critical Raw Materials to the EU (HREEs = Heavy Rare Earth Elements[10], LREEs = Light Rare Earth Elements[11], PGMs = Platinum Group Metals[12])

The revised methodology[13] brought several improvements: systematic screening of the most critical points in the supply chain (mining/extracting and processing/refining); inclusion of an import reliance parameter and a trade-related parameter based on export restrictions and the EU trade agreements; considering also the actual sourcing of the material to the EU (domestic production plus imports), not only the global supply; inclusion of substitution in both supply risk and economic importance and improving the calculations, while the previous assessments only addressed substitution in the supply risk; more specific allocation of raw materials to the relevant end-use applications and corresponding manufacturing sectors, instead of mega sectors etc.

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[5] EU Raw Materials Scoreboard 2016. https://publications.europa.eu/en/publication-detail/-/publication/1ee65e21-9ac4-11e6-868c-01aa75ed71a1/language-en

[6] The assessment is based on historical data rather than forecasts.

[7] Communication "Tackling the challenges in commodity markets and on raw materials", COM(2011) 25

[8] Communication "On the review of the list of CRM for the EU and the implementation of the Raw Materials Initiative", COM(2014) 297

[9] Communication on the 2017 list of Critical Raw Materials for the EU, COM(2017) 490

[10] dysprosium, erbium, europium, gadolinium, holmium, lutetium, terbium, thulium, ytterbium, yttrium

[11] cerium, lanthanum, neodymium, praseodymium, samarium

[12] iridium, platinum, palladium, rhodium, ruthenium

[13] https://publications.europa.eu/en/publication-detail/-/publication/2d43b7e2-66ac-11e7-b2f2-01aa75ed71a1/language-en/format-PDF http://www.sciencedirect.com/science/article/pii/S0301420717300223?via%3Dihub

1.1.2. Global situation in supply and trade

The European industry is dominated by the manufacturing industry (i.e. the manufacture of end products and applications) and also the refining industry (metallurgy, etc.), compared to the extractive industry (mine and carriers). The value chain of CRMs is not fully and homogeneously covered by the European industry. Pronounced imbalance exists between the upstream steps (extraction / harvesting) and the downstream steps (manufacturing and use). Considering the very limited supply of CRMs from secondary sources[14] (see Fig. 5 and Fig. 7), the need for access to primary sources, including ores, concentrates, processed or refined materials is huge and crucial for the wealth – and even the survival – of European industries and their associated jobs and economic benefits.

The majority of these primary raw materials are produced and supplied from non-European countries.

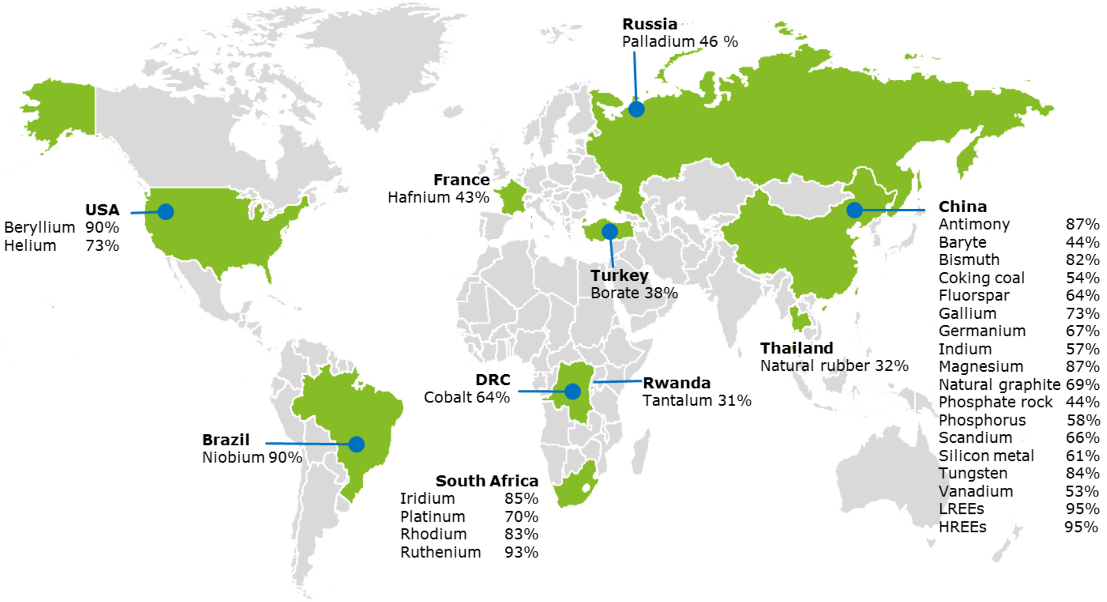

Figure 1: Contribution of primary global suppliers of critical raw materials, average from 2010-2014

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[14] I.e. from recycling of waste

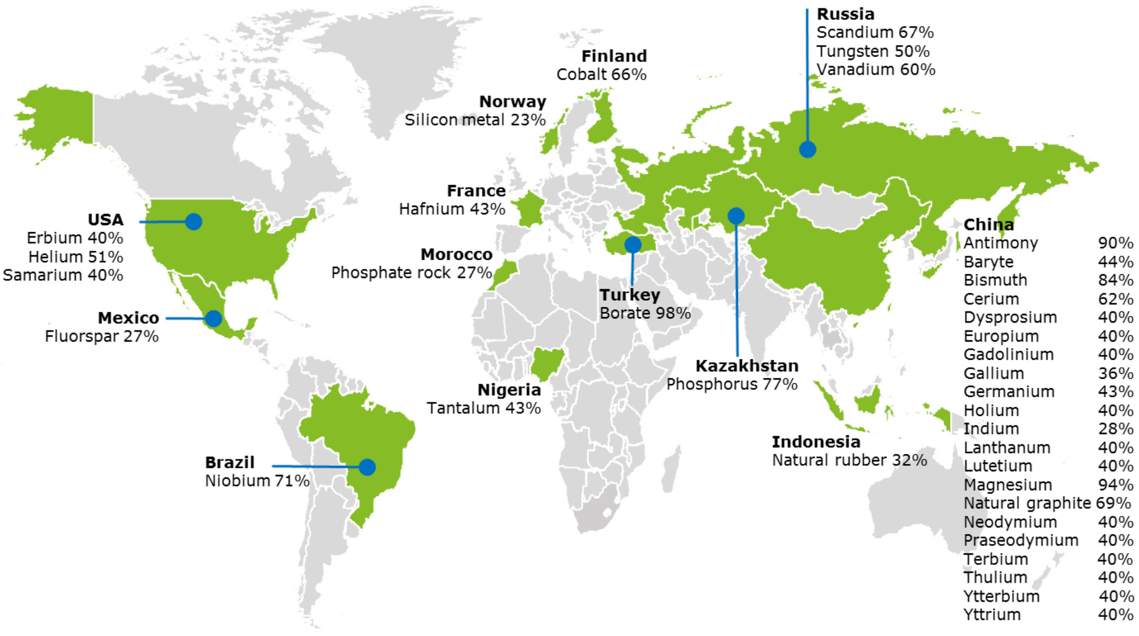

Figure 2: Contribution of countries accounting for largest share of supply of primary CRMs to the EU, average from 2010-2014

Although China is also the principal supplier of CRMs to the EU, the analysis highlights several other countries that represent important shares of the EU supply for specific CRMs, such as the USA (beryllium and helium), Russia (cobalt and scandium) and Mexico (fluorspar and tungsten). The revised methodology incorporates actual sourcing to the EU, therefore allows for a more realistic picture of Europe's supply of the raw materials assessed.

For many CRMs the upstream steps of the value chain are not present in the EU: antimony, beryllium, borates, magnesium, niobium, PGMs, phosphorus, rare earths, scandium, tantalum and vanadium. This is due either to the absence of those materials in the European ground or to economic and societal factors that negatively affect the exploration (for deposit discovery and characterisation, estimation of resources and reserves) or the extraction (closure of existing mines, reluctance to open new mines, etc.). In addition to abiotic raw materials, natural rubber is also grown and harvested entirely outside the EU.

To access those primary CRMs, the EU has currently no other choice than importing the ores and concentrates or the refined materials from other countries to feed its industries and markets.

Hafnium is the only CRM for which an EU Member State (France) is the global main producer. For hafnium and indium, the Member States produce enough primary materials to avoid significant extra-European imports.

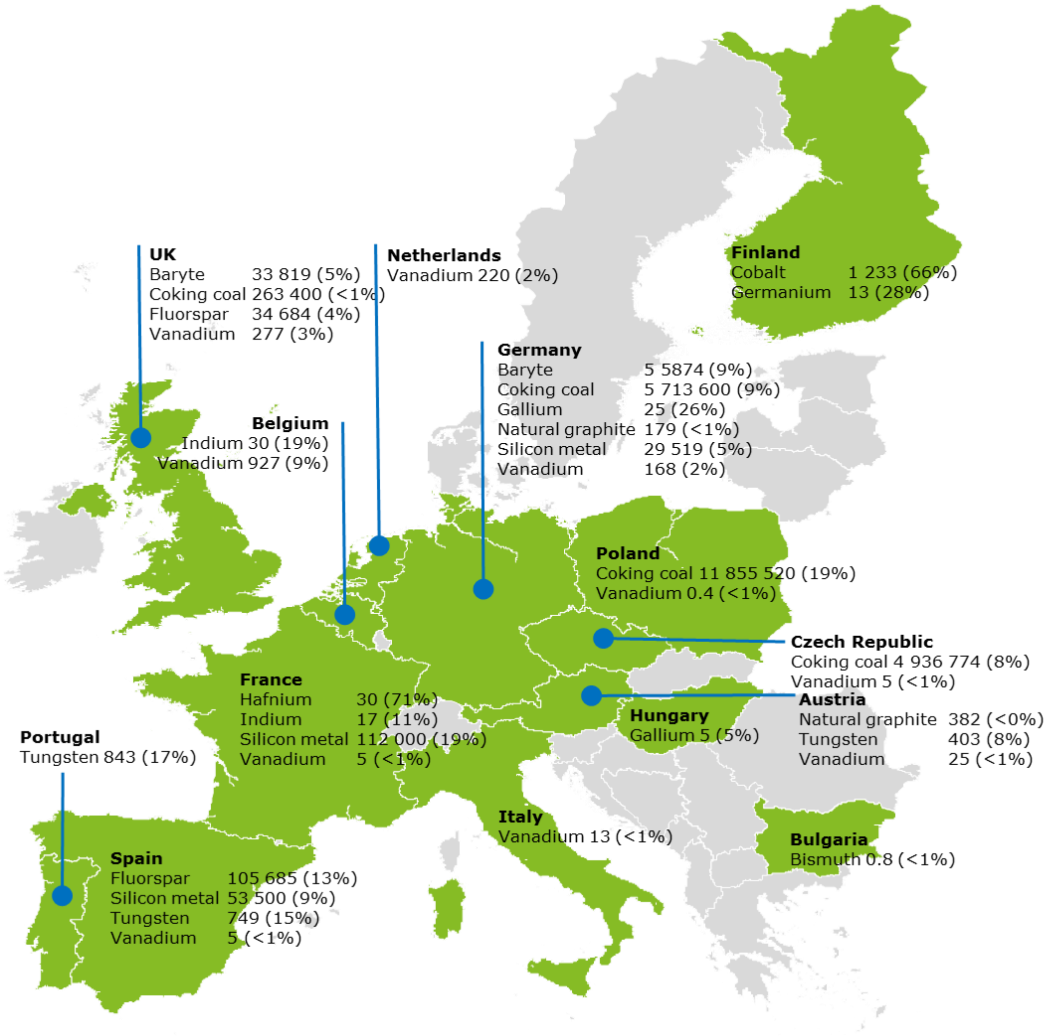

Figure 3: EU production of primary CRMs in tonnes (and share of supply to EU), average from 2010-2014

1.2. Circular economy

1.2.1. Background and definition

On 2 December 2015, the Commission adopted a Circular Economy package consisting of a Communication and an action plan[15] and proposals for revised legislation on waste[16]. It indicated that 'the transition to a more circular economy, where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimised, is an essential contribution to the EU's efforts to develop a sustainable, low carbon, resource efficient and competitive economy.'

The actions support the circular economy in each step of the value chain – from production to consumption, repair and remanufacturing, waste management, and secondary raw materials that are fed back into the economy.

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[15] COM(2015) 614

[16] COM(2015) 593, COM(2015) 594, COM(2015) 595 and COM(2015) 596

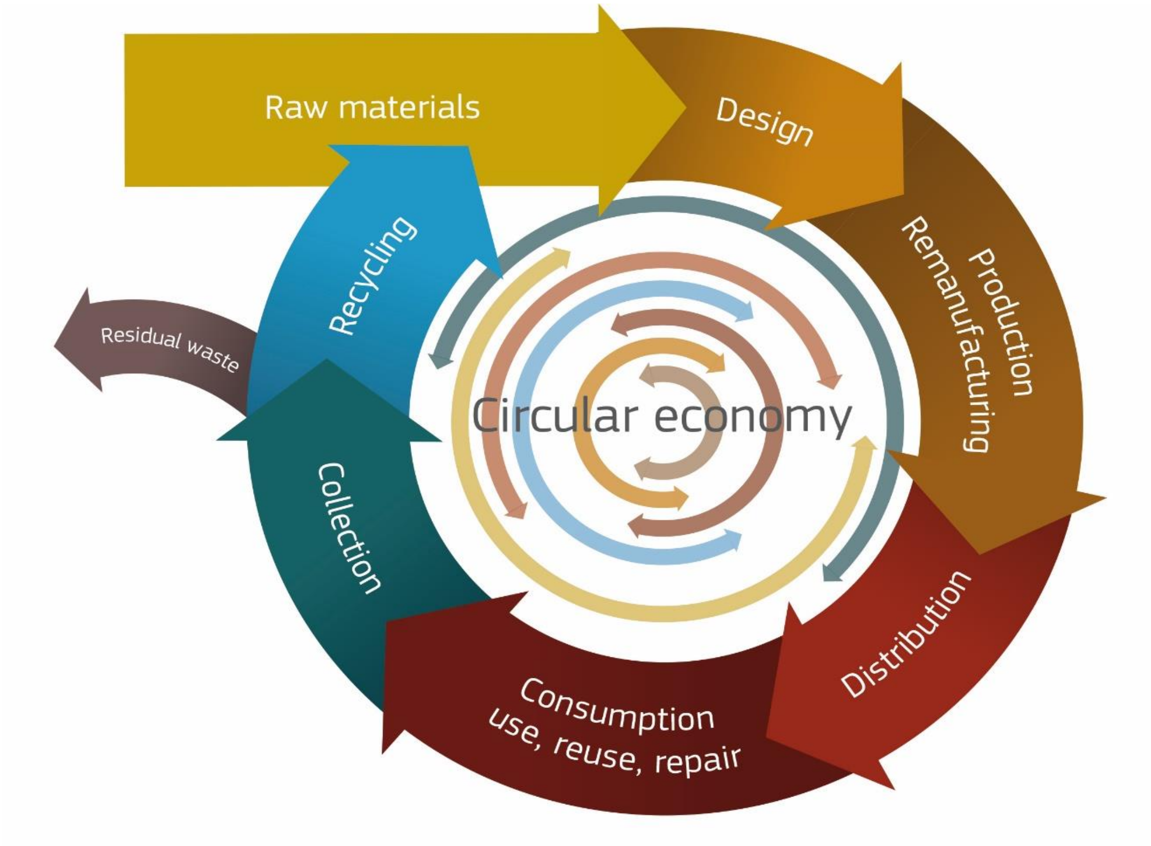

Figure 4: Conceptual diagram illustrating the Circular Economy in a simplified way

Economic actors, such as business and consumers, are key in driving this process. Local, regional and national authorities are enabling the transition, but the EU also has a fundamental role to play in supporting it. The aim is to ensure that the right regulatory framework is in place for the development of the circular economy in the single market, and to give clear signals to economic operators and society at large on the way forward with long term waste targets as well as a concrete, broad and ambitious set of actions, to be carried out before 2020. Action at EU level will drive investments and create a level playing field, remove obstacles stemming from European legislation or inadequate enforcement, deepen the single market, and ensure favourable conditions for innovation and the involvement of all stakeholders.

1.2.2. Current circular use of critical raw materials

While there is no universally agreed definition of 'circular use' of raw materials, the share of secondary sources in raw material supply is one of several simplified approaches to assess circular use.

Although several CRMs have a high technical and real economic recycling potential, and despite the encouragement from governments to move towards a circular economy, the recycling input rate (a measure of the share of secondary sources in raw material supply) of CRMs is generally low (see Fig. 5). This can be explained by several factors: sorting and recycling technologies for many CRMs are not available yet at competitive costs; the supply of many CRMs is currently locked up in long-life assets, hence implying delays between manufacturing and scrapping which negatively influences present recycling input rates; demand for many CRMs is growing in various sectors and the contribution from recycling is largely insufficient to meet the demand.

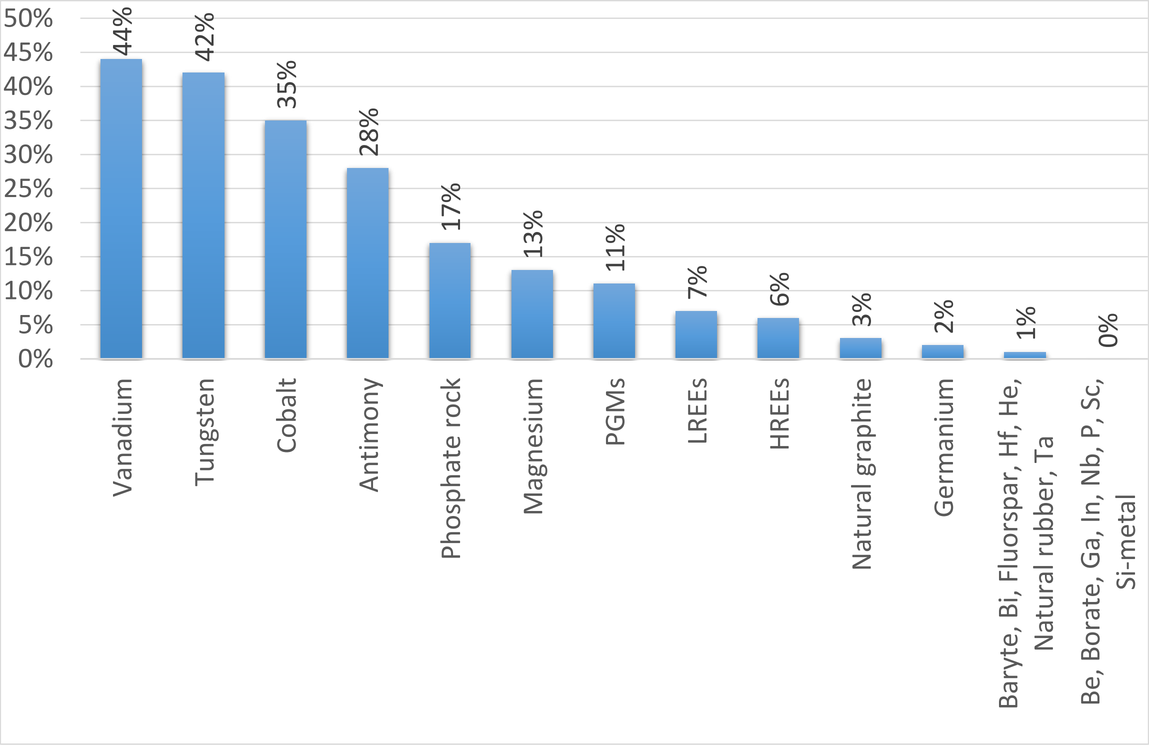

Figure 5: Current contribution of recycling to meet EU demand of CRMs: End-Of-Life recycling Input Rate (EOL-RIR) (JRC elaboration based on the 2017 CRM study and on the MSA study 2015)

A few CRMs, namely Vanadium, Tungsten, Cobalt and Antimony have a high recycling input rate. Other CRMs have a good rate of recycling at end-of-life (e.g. recycling rates for PGMs reaches up to 95% for industrial catalysts and 50-60% for automotive catalysts) but this gives a contribution that is largely insufficient to meet the growing demand and thus the recycling input rate is low (e.g. 14% for PGMs).

As a summary, the circular use of CRMs depends on many parameters. It should be pointed out that circularity is very much influenced by the sectors in which CRMs are used: the demand and the duration of the use of the CRMs is strictly dependant on the products that the CRMs are embodied in, recycling rates usually depend on the nature of the end-of-life products the CRMs are embodied in; moreover, circularity of several CRMs strongly benefits from take back-scheme that are implemented in various sectors. (See Section 5 of this report for key sector overviews.) The need to adopt a sectorial analysis for the analysis of flows of CRMs, including considering circularity aspects, was confirmed by a recent report of the SCRREEN project (see Section 3.4).[17]

1.2.3. *Benefits of a more circular use*

Just as extraction of primary CRMs in Europe helps to ensure **security of supply** of raw materials to European industry, so does their resource efficient management throughout the lifecycle and the recycling of waste into secondary CRMs. Consequently, substitution and recycling are considered as risk reducing measures in the methodology for establishing the EU list of Critical Raw Materials[18].

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[17] Report on the current use of critical raw materials. http://scrreen.eu/wp-content/uploads/2017/01/SCRREEN-D2.1-Report-on-the-current-use-of-critical-raw-materials.pdf

[18] http://publications.europa.eu/en/publication-detail/-/publication/2d43b7e2-66ac-11e7-b2f2-01aa75ed71a1/language-en/format-PDF/source-32064602

Energy use (and associated CO_2 emissions and other emissions to air) and **water use** are typically much lower for secondary CRMs than for primary CRMs. Some examples are given in Table 2.

Metal	**Energy use** (MJ per kg of metal extracted)		**Water use** (m^3 per tonne of metal extracted)	
	Scrap	Ores	Scrap	Ores
Magnesium	10	165-230	2	2-15
Cobalt	20-140	140-2100	30-100	40-2000
PGM	1400-3400	18,860-254,860	3000-6000	100,000-1200,000
Rare Earths	1000-5000	5500-7200	250-1250	1275-1800

Table 2: Energy and water consumption in production of metals from scrap and ores (range given is high to low grade)[19]

Other environmental benefits of a more circular use may include for instance lower impacts on the biosphere (rainforests, arctic regions, ocean floors etc.) and/or less waste produced per tonne of material extracted.

2. GENERAL POLICY MEASURES

2.1. Waste Framework Directive

The Waste Framework Directive[20] provides for a general framework of waste management requirements and sets the basic waste management definitions for the EU. As for its future direction, the 7th Environment Action Programme sets the following priority objectives for waste policy in the EU:

- To reduce the amount of waste generated;
- To maximise recycling and re-use;
- To limit incineration to non-recyclable materials;
- To phase out landfilling to non-recyclable and non-recoverable waste;
- To ensure full implementation of the waste policy targets in all Member States.

Following a review of the Directive, the Commission adopted a proposal for changes to the Directive in December 2015 as part of its Circular Economy package. Of particular relevance are the proposed provisions on CRMs i.e. that Member States should take measures to achieve the best possible management of waste containing significant amounts of CRMs, taking economic and technological feasibility and environmental benefits into account, prevent products constituting the main sources of CRMs from becoming waste and include in their waste management plans nationally appropriate measures regarding collection and recovery of waste containing significant amounts of CRMs. The present report should help Member States implement the proposed provisions on CRMs.

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[19] Sverdrup and Koca, "*A short description of the WORLD 6.0 model and an outline of elements of the standard parameterization*", 2016

[20] Directive 2008/98/EC of the European Parliament and of the Council on waste

2.2. Circular Economy Finance Support Platform

The European Fund for Strategic Investments (EFSI) is an initiative to help overcome the current investment gap in the EU. Jointly launched by the European Investment Bank (EIB) Group and the Commission, it aims to mobilise private investment in projects which are strategically important for the EU.

Linked to EFSI, a platform to support the financing of circular economy was launched together with the Commission's first report on the implementation of the Circular Economy Action Plan[21]. The platform brings together the Commission, the EIB, financial market participants and businesses to increase awareness of the circular economy business logic and improve the uptake of circular economy projects by investors.

The platform has a three-pillar structure:

- The coordination and awareness raising pillar will share best practices amongst potential project promoters and other stakeholders. It will analyse the characteristics of circular economy projects and their particular financing needs, advice on improving their bankability, as well as coordinate activities regarding financing of the circular economy. In this context, a Support to Circular Economy Financing Expert Group has been set-up. The first meeting of this expert group was held on 2 October 2017.
- The advisory pillar will be used to develop circular economy projects and to improve their bankability prospects.
- The financing pillar will explore whether a dedicated financing instrument for circular economy projects is needed.

2.3. Horizon 2020

Horizon 2020 has been instrumental in implementing the EU Raw Materials Initiative and the European Innovation Partnership (EIP) on Raw Materials (See Section 3.1). Particularly the Societal Challenge 5 on climate action, environment, resource efficiency and raw materials (SC5) has helped to respond to the challenge of securing the sustainable access to raw materials, particularly CRMs. Other major contributing parts of Horizon 2020 include the SPIRE Public Private Partnership on energy efficient raw materials production and the Nanotechnologies, Advanced Materials, Biotechnology and Advanced Manufacturing and Processing work programmes.

More than €200 million has so far been invested in R&I actions under the SC5 developing and demonstrating sustainable production of primary and secondary raw materials, including CRMs, in the EU. The Commission already funded at least 26 research projects and policy support actions related to CRMs (see further in Section 3). All the actions should help to consolidate a growing raw materials R&I community in Europe and outside. The started or planned large innovation actions are expected to contribute to achieving the EIP target of launching at least ten innovative pilot plants for the production of raw materials and finding at least three substitutes of CRMs. Raw materials topics under the SC5 are successfully attracting industrial participation: 43% of funding goes to private companies, compared to an average 28% in SC5 as a whole.

In the last period of 2018-2020, more than €250 million will be dedicated to the actions on raw materials, including more than €100 million under a Circular Economy Focus Area. The actions should contribute to improving access to CRMs and increased recovery

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[21] COM(2017) 33 final

rates in the EU, to reduced EU dependency on imports of CRMs and to strengthening the expert community in the EU.

2.4. Best practices

- France: *Le Comité pour les Métaux Stratégiques* (COMES) seeks to strengthen the security of supply of strategic metals. Its activities include work on specific recycling targets for strategic metals as part of certain extended producer responsibility (EPR) schemes.[22] The French agency ADEME also commissioned and published a study on research and development priorities for the recycling of critical metals.[23]
- The Netherlands: A Government-wide Programme for a Circular Economy[24] addresses critical mineral raw materials by promoting their substitution, efficient use, re-use and recycling. The Ministry of Economic Affairs has also commissioned the development of a "resource scanner", a method and IT tool to map out business risks.
- ERA-MIN 2: Through the Horizon 2020 programme, the Commission is co-funding ERA-MIN 2 which is the largest network of R&I funding organisations in the mineral resources field. It is a public-public partnership of 21 research funding organisations from 11 Member States, two regions and five non-EU countries[25]. In February 2017, a joint call, "Raw materials for the sustainable development and the circular economy", was published, including a topic on design of products: efficient use or substitution of critical materials in products and components, product durability, facilitation of recycling.[26]

2.5. Possible further actions

- The Commission could hold a workshop for Member States in 2018/2019 on approaches to implement the proposed provisions on CRMs under the Waste Framework Directive.

3. KEY ACTORS AND PROJECTS IN THE EU

3.1. The European Innovation Partnership on Raw Materials

The 2012 Communication proposing a European Innovation Partnership (EIP) on Raw Materials[27] asked EU and national industry, institutional stakeholders, academia, research organisations and NGOs to come up with a plan to contribute to the mid- and long-term security of the sustainable supply of raw materials in Europe. A strategic implementation plan was adopted in 2013.

Two calls for commitments from external stakeholders to implement the plan were launched in 2013 and 2015. As a result, there are currently some 105 ongoing recognised 'raw materials commitments'.[28] Several of these address CRMs and circular economy

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[22] http://www.mineralinfo.fr/page/comite-metaux-strategiques

[23] http://www.ademe.fr/sites/default/files/assets/documents/competences-recyclage-metaux-201706-rapport.pdf

[24] 'A Circular Economy in the Netherlands by 2050', September 2016, https://www.government.nl/documents/policy-notes/2016/09/14/a-circular-economy-in-the-netherlands-by-2050

[25] Finland (Tekes), France (ANR and ADEME), Germany (Juelich/BMBF), Ireland (GSI), Italy (MIUR), Poland (NCBR), Portugal (FCT), Romania (UEFISCDI), Slovenia (MIZS), Spain (CDTI and MINECO) and Sweden (Vinnova); Flanders (FWO and Hermesfonds) and Castille y Léon (ADE); Turkey (TUBITAK), Argentina (MINCyT), Brazil (Finep), Chile (CONICYT) and South Africa (DST).

[26] https://www.era-min.eu/system/files/call_text_era-min_joint_call_2017_0.pdf

[27] COM(2012) 82, 29.2.2012

[28] See https://ec.europa.eu/growth/tools-databases/eip-raw-materials/en/call-commitments

aspects. Calls for commitments offer an opportunity for stakeholders to receive a guarantee that their initiative is in line with the objectives of the EIP, get visibility and identify potential synergies with other initiatives in this area. In 2017, the memberships of the high-level steering group and the operational groups have been renewed.

3.2. The Ad hoc Working Group on Critical Raw Materials

The Ad hoc Working Group (AhWG) on Critical Raw Materials is a sub-group of the Commission expert group called the Raw Materials Supply Group[29]. It is composed of representatives from EU Member States, European Economic Area countries, candidate countries and organisations representing industry, research and civil society stakeholders.

The AhWG assists the Commission in the regular updates of the list of the CRMs and contributes with relevant expertise. It was also consulted on the outline of the present report.

3.3. The European Institute of Innovation and Technology: Raw Materials Knowledge and Innovation Community (EIT Raw Materials)

EIT RawMaterials, initiated by the EIT (European Institute of Innovation and Technology) and co-funded under Horizon 2020, is the largest consortium in the raw materials sector worldwide. It aims to boost competitiveness, growth and attractiveness of the European raw materials sector via driving and fostering innovation and empowering students, education partners and entrepreneurs toward the circular economy. This will result in the introduction of innovative and sustainable products, processes and services, as well as talented people that will deliver increased economic, environmental and social sustainability to European society.

EIT RawMaterials unites more than 100 partners – academic and research institutions as well as businesses – from more than 20 EU countries. They collaborate on finding new, innovative solutions to secure the supplies and improve the value chain of raw materials, including CRMs, from extraction to processing, manufacturing, reuse and recycling. There are six regional hubs ("co-location centres) in Belgium, Finland, France, Italy, Poland and Sweden that promote bridging between business, research and education.

3.4. SCRREEN: the European Expert Network on Critical Raw Materials

SCRREEN (Solutions for CRitical Raw materials - a European Expert Network)[30] is a new Coordination and Support Action funded under Horizon 2020. It aims at gathering European initiatives, associations, clusters, and projects working on CRMs into a long-lasting European expert network on CRMs with stakeholders, public authorities and civil society representatives. This network builds on the previous experience of the ERECON network (see below) and combines forces to address key CRM issues including circular economy aspects in relation with policy/society, technology, standards and markets.

SCRREEN will contribute to the CRM strategy in Europe by (i) mapping primary and secondary resources as well as substitutes of CRMs, (ii) estimating the expected demand of various CRMs in the future and identifying major trends, (iii) providing policy and technology recommendations for actions improving the production and the potential substitution of CRMs, (iv) addressing specifically waste electrical and electronic equipment (WEEE) and other relevant end-of-life products with regard to CRM contents and treatment standards and (vi) identifying the knowledge gained over the last years and easing the access to these data beyond the project. The knowledge gathered within the

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[29] http://ec.europa.eu/transparency/regexpert/index.cfm?do=groupDetail.groupDetail&groupID=1353

[30] http://scrreen.eu

project will be maintained in the EU Raw Materials Information System (see Section 4.1.1).

3.5. ERECON: The European Rare Earths Competency Network (2013-2015)

The former European Rare Earths Competency Network (ERECON)[31] brought together experts from industry, academia and policy-making to specifically look at ways to improve the security of Europe's **rare earth** supply. Three Working Groups of ERECON were focused on primary supply of rare earths in Europe; European rare earths resource efficiency and recycling; and European end-user industries and rare earths supply trends and challenges. Key findings of the network were compiled into a final report[32].

3.6. Other Horizon 2020 and LIFE projects

Together with the SCRREEN coordination and support action a number of **Horizon 2020** research and innovation actions are currently investigating the potential substitution of CRMs. **INREP**[33] and **INFINITY**[34] are working towards indium-free transparent conducting oxides. **Flintstone2020**[35] deals with the next generation of superhard non-CRM materials and solutions in tooling substituting tungsten and cobalt.

In the area of industrial symbiosis, **SCALE**[36] aims to develop a European supply chain for scandium through the development of technological innovations which will allow the extraction of scandium from bauxite residues, the **CHROMIC**[37] project aims to develop a new recovery process for critical by-product metals (niobium and vanadium) from complex and low-grade secondary industrial waste, **CABRISS**[38] aims at the recovery and preparation for reuse of key photovoltaic raw materials including silicon and indium, to be used for the manufacturing of photovoltaic cells and panels or as feedstock for other industries and **REslag**[39] is addressing, among other things, CRMs to be extracted from steel slag.

The **LIFE Programme** (2014-2020) also contributes to sustainable use, recovery and recycling of raw materials. It is currently funding a cluster of projects dealing with CRMs such as indium, platinum group metals and magnesium. Examples of such projects are the **CRM Recovery**[40] that is demonstrating viable approaches to increase the recovery of target CRMs found in waste electrical and electronic equipment through trials in Italy, Germany, the UK and the Czech Republic and the **RECUMETAL** project[41] that is demonstrating the recycling of flat panel displays to recover plastics, indium and yttrium and their reuse in new applications.

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[31] https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/erecon_en

"*Strengthening of the European Rare Earths Supply Chain - Challenges and policy options*", http://ec.europa.eu/DocsRoom/documents/10882/attachments/1/translations

[33] http://www.inrep.eu

[34] https://infinity-h2020.eu

[35] http://flintstone2020.eu

[36] http://scale-project.eu/

[37] http://www.chromic.eu/

[38] https://www.spire2030.eu/cabriss

[39] http://www.reslag.eu

[40] http://www.criticalrawmaterialrecovery.eu/

[41] https://life-recumetal.eu/en/

4. DATA SOURCES AND MONITORING

4.1. Multi-sector data sources

4.1.1. The EU Raw Materials Information System including the CRM fact sheets

Securing undistorted supply of raw materials and, in particular, CRMs requires a sound and continuously updated knowledge base. In this context, and responding to a specific action of the 2015 Circular Economy Communication, the Commission is developing the EU Raw Materials Information System (RMIS)[42]. The first version (RMIS 1.0) was launched in March 2015. The advanced RMIS 2.0 version, launched in November 2017, is intended as a one-stop information gateway and knowledge service centre for non-energy, non-food primary and secondary raw materials.

Figure 6: Front page of the EC's Raw Material Information System (RMIS2.0)

RMIS 2.0 is to (a) support EU policy with tailor-made applications like the periodical Raw Material Scoreboard (see Section 4.2.1) and criticality assessments, and (b) help coordinate other EU level data and information on raw materials for the benefit of a variety of users. This will be made available directly in RMIS from different data sources. It will be facilitated by enhanced cooperation with Member States, industry representatives, and other stakeholders. Different functionalities of RMIS 2.0 will directly serve the implementation of the circular economy policy. Examples include Material Flow Analysis (MFA) and Material System Analysis (MSA, see below); information and data on secondary raw materials; contents on sustainability aspects and on research & innovation.

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[42] http://rmis.jrc.ec.europa.eu

RMIS 2.0 makes easily available and further exploitable the huge amount of information and data collected during the criticality assessments, which represent the background of the lists of CRMs. Such information and data is compiled and systematically organised in **raw materials factsheets** that provide ample information on each of the CRMs (and certain non-critical raw materials). The factsheets include information on supply from mining / harvesting, supply from recycling, trade, end-uses and related economic sectors, substitution, as well as supply chain analysis. Key facts and figures are collected and summarised on the front page of each factsheet.

4.1.2. Material System Analysis

In 2015, the Commission published a study[43] on Material System Analysis (MSA). It investigates the flows and stocks of 28 raw materials (26 individual CRMs plus aggregates and lithium) from "cradle-to-grave" across the entire material life cycle from resource extraction to materials processing, manufacturing and fabrication to use and subsequent collection, processing and disposal or recycling.

The 2015 MSA study provides an overview of data sources, with a specific examination of the Eurostat database on trade of goods from the viewpoint of its usability for MSA, a detailed methodology and a material system analysis for the 28 studied materials with data sources, assumptions and calculations and with main data gaps filled with experts' inputs gathered through direct consultations and organisation of workshops. It also contains recommendations for the maintenance and update of the MSA.

For each material, the MSA includes a Sankey diagram with material flows (as raw materials, components or products) illustrating entry (extraction, imports) and movement (production, consumption, exports) through the EU economy, additions to stock, and end-of-life disposal or recovery; and information on security of supply (country concentration) and substitutes.

By tracking materials throughout their full life cycle, the MSA can help to quantify potential primary and secondary sources and support the monitoring of their "level of circularity" in the EU-28. This is particularly important for CRMs for which public information on their trade is sometimes unknown, their uses have not been well documented, and their levels of recovery and reuse once discarded are generally low. An accurate assessment of global and EU-wide mineral resources must include not only the resources available in the ground (reserves) but also those that are present as stocks within the technosphere and become available through recycling. The data resulting from the 2015 MSA study provides an important base of background information from which security of supply and sustainable development pathways can be designed.

4.1.3. ProSUM

ProSUM[44] (Prospecting Secondary raw materials in the Urban mine and Mining waste) is a Coordination and Support Action funded by Horizon 2020 establishing a European network of expertise on secondary sources of CRMs. The project is providing data about stocks, flows, waste arisings and treatment of various product groups that are highly relevant as potential secondary sources of CRMs, i.e. waste electrical and electronic equipment (WEEE), end-of-life vehicles (ELVs), batteries and mining wastes.

Information concerning products placed on the market, product stocks and waste flows in the EU derive from both measured data, coherent estimates based on statistical

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[43] 'Study on Data for a Raw Material System Analysis (MSA): Roadmap and Test of the Fully Operational MSA for Raw Materials'. https://ec.europa.eu/jrc/en/scientific-tool/msa

[44] http://www.prosumproject.eu/

information, experts' assumptions and extrapolation. Quality level, uncertainty and error propagation of the gathered information are harmonised in order to provide high quality data in a centralised **Urban Mine Knowledge Data Platform**. Moreover, the data structure eases the regular update and maintenance of the information.

ProSUM has produced an EU-wide data platform providing user-friendly, seamless access to data and intelligence on secondary raw materials in various wastes. It provides centralised access to charts and maps and includes a search engine currently covering over 800 data sources and documents structured by the ProSUM project. This deliverable is key for the creation of a European raw materials knowledge base and it is contributing to the above-mentioned EU Raw Material Information System.

4.1.4. General sources

No	Name and link/ref.	Scope			Reference period / date of publ.	Language	Free / subscription	Comments
		Subsectors	CRMs	Geographic area				
1	EU Raw Materials Information System[45]	Various	All	EU and Worldwide	2015/2017	English	Free	
2	Criticality studies prepared for the European Commission[46]	Various	All	EU and Worldwide	2014, 2017 (updated every 3 years)	English	Free	
3	MSA study[47]	Various	CRMs (2014)	EU	2015	English	Free	
4	Sebastiaan, D., Mancheri, N, Tukker, A, Brown, T., Petavratzi, E., Tercero Espinoza, L. (2017): Report on the current use of critical raw materials[48]	Various	2014 list of CRMs	EU	2017	English	Free	
5	Marscheider-Weidemann, F., Langkau, S., Hummen, T., Erdmann, L., Tercero Espinoza, L., Angerer, G., Marwede, M. & Benecke, S. (2016): Rohstoffe für Zukunftstechnologien 2016. DERA Rohstoffinformationen 28; 353 S., Berlin. March 2016. [49]	Emerging technologies	Several	Germany	2016	German	Free	'Raw materials for emerging technologies 2016'
6	Graedel, T. E., J. Allwood, J. P. Birat, B. K. Reck, S. F. Sibley, G. Sonnemann, M. Buchert, and C. Hagelüken (2011): Recycling Rates of Metals – A Status Report. UNEP International Resource	All	Several	Worldwide	2011	English	Free	

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[45] http://rmis.jrc.ec.europa.eu

[46] https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

[47] https://ec.europa.eu/jrc/en/scientific-tool/ msa

[48] http://scrreen.eu/wp-content/uploads/2017/01/SCRREEN-D2.1-Report-on-the-current-use-of-critical-raw-materials.pdf

[49] https://www.bgr.bund.de/DERA/DE/Downloads/Studie_Zukunftstechnologien-2016.pdf;jsessionid=A996A13E9E2764B203496C746AB0D6D4.1_cid284?__blob=publicationFile&v=5

	Panel.							
7	EASAC policy report 29 (2016): Priorities for critical materials for a circular economy.[50]	All	All	World-wide	2016	English	Free	
8	ADEME (2010): Etude du potentiel de recyclage de certains métaux rares.	Various	35 metals including Rare Earths	World-wide	2010	French	Free	
9	Schuler D. et al. (2011). Study on Rare Earths and their Recycling.[51]	Various	Rare Earths	World-wide	2011	English	Free	
10	Du X. and Graedel T. (2011). Global in-use stocks of the rare earth elements: a first estimate.[52]	Various	Rare Earths	World-wide	2011	English	Sub-scription	
11	ETC/SCP (2011). Green economy and recycling in Europe.[53]	Various	Several	Europe/ World-wide	2011	English	Free	
12	Hagelüken C. and Meskers C. (2010). Complex Life Cycles of Precious and Special Metals. Strüngmann Forum Report, Linkages of Sustainability. Edited by Thomas E. Graedel and Ester van der Voet.	Various	Several	Europe/ World-wide	2010	English	Sub-scription	
13	Gunn G. (2013). Critical Metals Handbook. John Wiley & Son.	Various	Several	World-wide	2013	English	Sub-scription	
14	UNEP International Resource Panel (2010). Metal Stocks in Society: Scientific Synthesis	Various	Several	World-wide	2010	English	Free	

4.2. Monitoring progress

As mentioned in the introduction (section 1.2.2), there is no universally agreed definition of 'circular use' of raw materials. Even so, at EU level two interlinked means to monitor progress are presently available: the 'Raw Materials Scoreboard' and the ' Circular Economy Monitoring Framework '.

4.2.1. The Raw Materials Scoreboard

The Raw Materials Scoreboard is an initiative of the European Innovation Partnership on Raw Materials. The Scoreboard provides information on the EU's overall raw materials policy context. The first edition of the Scoreboard, published in 2016, consists of 24 indicators grouped into five thematic clusters.

The Scoreboard's thematic cluster on "Circular economy and recycling" consists of four complementary indicators: material flows in the circular economy, recycling's

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[50] http://www.easac.eu/fileadmin/PDF_s/reports_statements/Circular_Economy/EASAC_Critical_Materials_web_corrected_Jan_2017.pdf

[51] http://www.oeko.de/oekodoc/1112/2011-003-en.pdf

[52] Environmental Science and Technology, 45(9), 4096-101

[53] http://scp.eionet.europa.eu/publications/2011_wp5/wp/WP2011_5

contribution to materials demand, management of waste electrical and electronic equipment (WEEE) and trade in secondary raw materials.

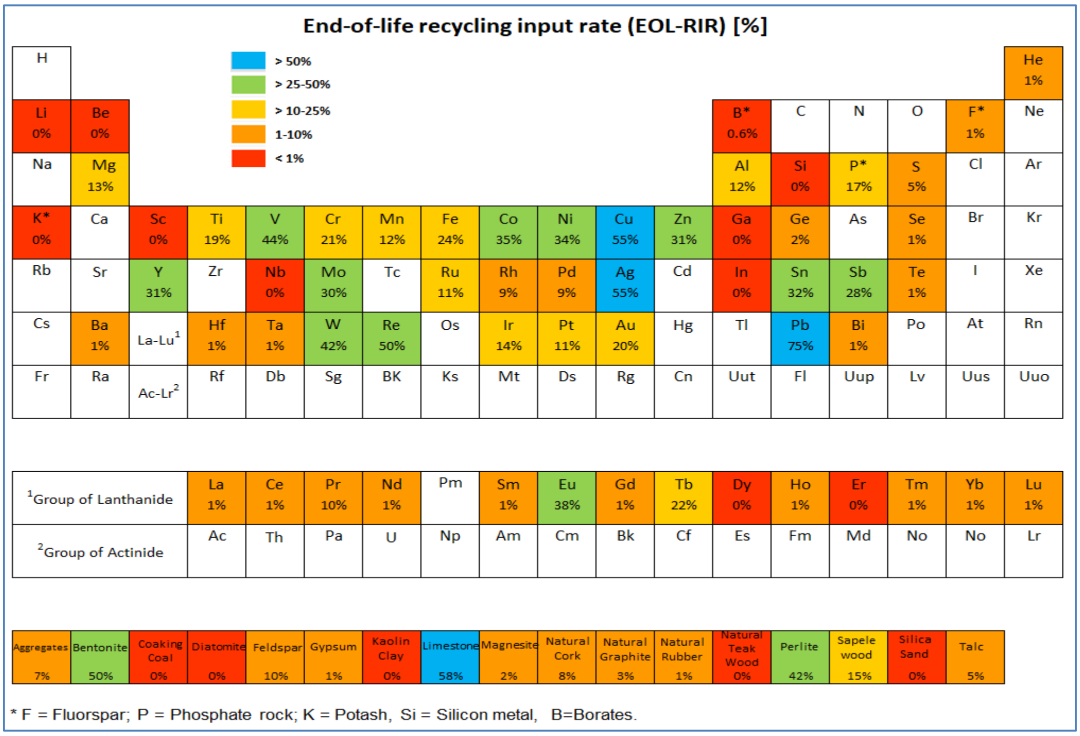
Two of these indicators are particularly relevant for CRMs. The indicator on recycling's contribution shows that for almost all CRMs the contribution of recycled materials to raw materials demand is small to negligible. The indicator on WEEE management, a waste stream that contains significant amounts of CRMs, further provides information on collection and recycling. It shows that the levels of collection, reuse and recycling of WEEE vary considerably across EU Member States, indicating a significant potential to improve resource efficiency.

4.2.2. *The Circular Economy Monitoring Framework*

The circular economy monitoring framework[54] is a set of 10 indicators that aim at assessing progress towards a more circular economy and the effectiveness of action at EU and national level.[55]

Several indicators included in the circular economy monitoring framework are relevant to CRMs, including the indicator on self-sufficiency for raw materials, the (sub)indicator on recycling rates of WEEE and the indicator on the contribution of recycled materials to raw materials demand (all three are also indicators in the Raw Materials Scoreboard).

Figure 7 presents the contribution of recycled materials to materials demand for a number of raw materials. It shows that even for materials for which overall recycling rates are relatively high, recycling's contribution to meeting materials demand is relatively low. This is because demand is higher than what can be met by recycling. In other cases, functional recycling is not economically feasible.



End-of-life recycling input rate (EOL-RIR) [%]

🟦 > 50%
🟩 > 25-50%
🟨 > 10-25%
🟧 1-10%
🟥 < 1%

H																	He 1%
Li 0%	Be 0%											B* 0.6%	C	N	O	F* 1%	Ne
Na	Mg 13%											Al 12%	Si 0%	P* 17%	S 5%	Cl	Ar
K* 0%	Ca	Sc 0%	Ti 19%	V 44%	Cr 21%	Mn 12%	Fe 24%	Co 35%	Ni 34%	Cu 55%	Zn 31%	Ga 0%	Ge 2%	As	Se 1%	Br	Kr
Rb	Sr	Y 31%	Zr	Nb 0%	Mo 30%	Tc	Ru 11%	Rh 9%	Pd 9%	Ag 55%	Cd	In 0%	Sn 32%	Sb 28%	Te 1%	I	Xe
Cs	Ba 1%	La-Lu^1	Hf 1%	Ta 1%	W 42%	Re 50%	Os	Ir 14%	Pt 11%	Au 20%	Hg	Tl	Pb 75%	Bi 1%	Po	At	Rn
Fr	Ra	Ac-Lr^2	Rf	Db	Sg	BK	Ks	Mt	Ds	Rg	Cn	Uut	Fl	Uup	Lv	Uus	Uuo

^{1}Group of Lanthanide	La 1%	Ce 1%	Pr 10%	Nd 1%	Pm	Sm 1%	Eu 38%	Gd 1%	Tb 22%	Dy 0%	Ho 1%	Er 0%	Tm 1%	Yb 1%	Lu 1%
^{2}Group of Actinide	Ac	Th	Pa	U	Np	Am	Cm	Bk	Cf	Es	Fm	Md	No	No	Lr

Aggregates	Bentonite	Coaking Coal	Diatomite	Feldspar	Gypsum	Kaolin Clay	Limestone	Magnesite	Natural Cork	Natural Graphite	Natural Rubber	Natural Teak Wood	Perlite	Sapele wood	Silica Sand	Talc
7%	50%	0%	0%	10%	1%	0%	58%	2%	8%	3%	1%	0%	42%	15%	0%	5%

* F = Fluorspar; P = Phosphate rock; K = Potash, Si = Silicon metal, B=Borates.

Figure 7: End-of-life recycling input rates (EOL-RIR) in the EU-28 (CRMs and non-CRMs)[56], [57]

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[54] http://ec.europa.eu/eurostat/web/circular-economy

[55] As announced in the Circular Economy Action Plan, COM(2015) 614

5. KEY SECTORS (SUPPLY AND DEMAND OF CRITICAL RAW MATERIALS)

This section covers the main source of primary CRMs (mining) and other potential sources (mining waste and landfills), as well as the sectors where most CRMs are used, i.e. constituting the main sources of secondary CRMs (electrical and electronic equipment, batteries, automotive sector, renewable energy, defence industry, chemicals and fertilisers). (See also Annex I: Major applications of CRMs and information on recycling)

5.1. Mining

Extractive industries provide mineral raw materials that are essential to the downstream industries and economic sectors. Extractive industries provide, first of all, primary (critical) raw materials. In addition, mining waste provides a (potential) source of secondary (critical) raw materials.

5.1.1. Data and data sources

The inventory of the *primary* CRM deposits in the EU has been gradually built up in the Framework Programme 7 projects ProMine[58] and Minerals4EU[59] and also in the new Horizon 2020 ERA-NET GeoERA[60] driven by European geological surveys.

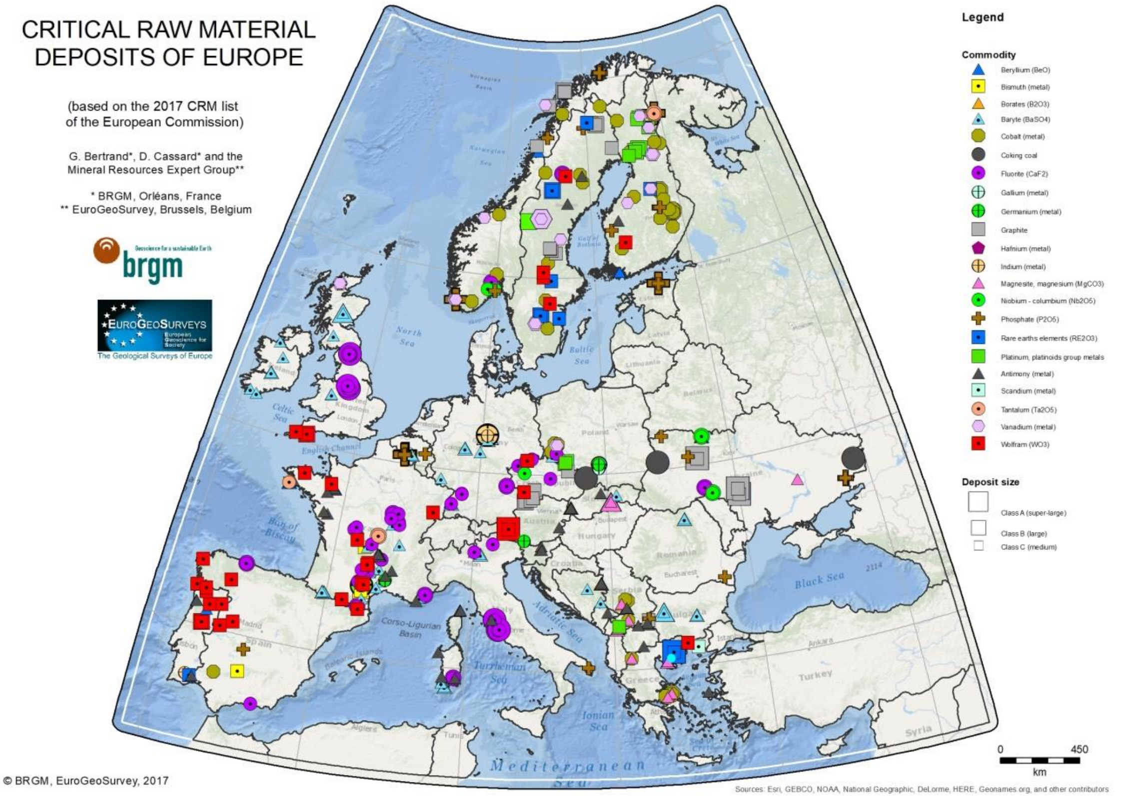

Figure 8: Map of CRM ore deposits in Europe

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[56] Source: JRC elaboration based on the EU list of Critical Raw Materials (2017) and MSA Study (2015). The European Commission acknowledges the existence of data gaps and inconsistencies and has initiated a number of steps in view of future data improvement.

[57] The 'end-of-life recycling input rate' (EOL-RIR) measures how much of the total material input into the production system comes from recycling of "old scrap". Elements in white indicate that no data or estimates are available from the 2017 EU criticality assessment.

[58] http://promine.gtk.fi

[59] http://www.minerals4eu.eu

[60] http://geoera.eu

The production data of 63 mineral commodities from 168 countries are annually published by the Austrian Federal Ministry of Science, Research and Economy in the publication "World Mining Data"[61] with quality of data indication. The British Geological Survey also publishes similar information in their World Mineral Production annual publication. EU Materials System Analysis and CRM studies and fact sheets use this information (see Figures 1, 3, 5).

As regards *secondary* CRMs extracted or extractable from mining waste, at present there is no detailed database at EU or Member State level although recent EU-funded projects are addressing this lack of comprehensive data and information, in particular the ProSUM project (see section 4.1.3).

The MSA study (see section 4.1.2) depicts extractive waste in the EU using the following two parameters:

- "Extraction waste disposed in situ/tailings" is the annual quantity of the element in the extraction waste disposed in situ. This indicator refers to tailings (waste from extraction and if applicable preliminary step of processing made in situ);
- "Stock in tailings" is the quantity of the element in tailings in EU. This amount corresponds to the "extraction waste disposed in situ/tailings" accumulated over time.

A preliminary analysis from the MSA study on annual flows and stocks of CRMs in extractive waste over the last 20 years is reported in Figure 9. Quantities are indicative and mostly derived from mass balances and expert assumptions. Moreover, CRMs accumulated in tailings have likely undergone chemical and physical changes, which must be further evaluated under several aspects, in view of their possible recovery.

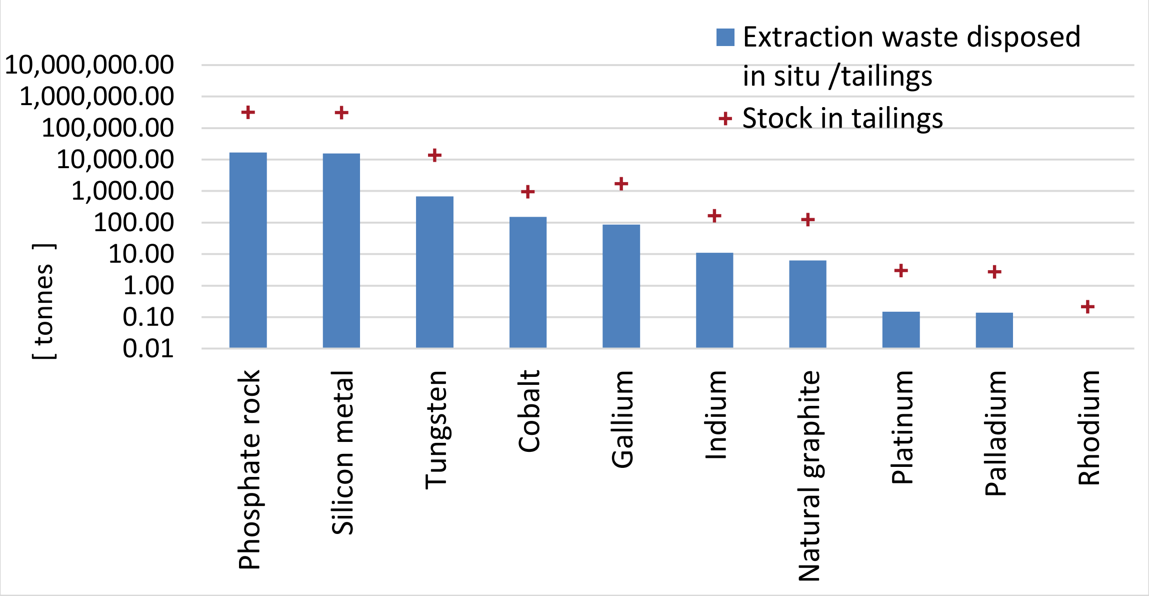

Figure 9: Amounts of some critical raw materials in EU-28 as "Extraction waste disposed in situ/tailings" and "Stock in tailings" (JRC elaboration based on MSA study (2015))

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[61] http://www.world-mining-data.info

Data Sources

No	Name and link/ref.	Scope			Reference period / date of publ.	Language	Free / subscription	Comments
		Subsectors	CRMs	Geographic area				
1	Eurostat PRODCOM[62]	Mining	Some	EU 28	2004-2014	English	Free	Data on production of minerals and metals
2	Eurostat[63]	Waste of mining and quarrying	-	EU 28	2004-2014	English	Free	Data on the generation of hazardous and non-hazardous waste by country and sector. Consistency is limited due to differing reporting methods.
3	Minerals4EU	Mining and mining waste	All	EU 28	2014-2015	English	Free	Mining waste data based on a flow and stock model
4	MSA study[64]	Mining and mining waste	CRMs (2014)	EU	2015	English	Free	
5	ProSUM[65]	Mining Waste	All	EU 28	2015-	English	Free	Data on stocks of secondary raw materials
6	SMART GROUND[66]	Mining Waste	All	EU 28 (with focus on Italy as case-study country)	2015-	English		Improving knowledge on CRMs, including characterisation of mining waste deposits for CRMs

5.1.2. *Existing EU policies*

In 2008 the Commission launched a '**Raw Materials Initiative**'[67] complementing Member States' national policies on raw materials. This strategy has three pillars which aim to ensure:

- Fair and sustainable supply of raw materials from global markets;
- Sustainable supply of primary raw materials within the EU;
- Resource efficiency and supply of secondary raw materials through recycling.

The mining and quarrying sector, as well as the forestry sector, have a key role to play under each of these pillars.

The **Extractive Waste Directive** (2006/21/EC) provides for measures, procedures and guidance to prevent or minimise adverse effects on the environment and human health resulting from the management of extractive waste. Under this Directive, Member States are required to ensure that operators in the extractive industry draw up a waste management plan for the minimisation, treatment, recovery and disposal of extractive

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[62] http://ec.europa.eu/eurostat/web/prodcom

[63] http://ec.europa.eu/eurostat/statistics-explained/index.php/Waste_statistics

[64] https://ec.europa.eu/jrc/en/scientific-tool/ msa

[65] http://www.prosumproject.eu/

[66] http://www.smart-ground.eu/

[67] http://ec.europa.eu/growth/sectors/raw-materials/policy-strategy

waste, taking account of the principle of sustainable development. This provision broadly follows the logic of circular economy.

The waste management plan shall aim at preventing or reducing extractive waste production and its harmfulness, in particular by considering waste management in the design phase and in the choice of the method used for mineral extraction and treatment. It shall also encourage the recovery of extractive waste by means of recycling, reusing or reclaiming waste, where this is environmentally sound.

A study was commissioned by the Commission to gather data on the implementation of the Extractive Waste Directive in Member States, including on policies and practices regarding the reprocessing of extractive waste. The report of this study was published in July 2017[68]. A few Member States[69] indicated that a dedicated strategy (or guidance) has been adopted encouraging the reprocessing of extractive waste. In a number of Member States[70] there is no dedicated strategy or guidance but relevant provisions are included as part of the wider national policy on waste or resource efficiency. Hungary has commissioned an assessment to identify the quality, quantity and possible exploitation options of the secondary raw materials in the extractive waste facilities. Nevertheless, the study concluded that, overall, Member State policies on reprocessing of extractive waste are limited and focusing more on utilisation of inert waste materials in construction than on innovative reprocessing of waste and tailings to extract value associated with valuable substances and minerals.

5.1.3. *Circular Economy Action Plan*

As announced in the Circular Economy Action Plan, the Commission has started working on the development of a document gathering best practices in the field of extractive waste management plans. Since the entry into force of the Extractive Waste Directive in 2008, operators have submitted waste management plans as part of their permit applications. By now, as a result of the many years of experience with such plans, a substantial knowledge base should have been established across the whole of the EU, which should enable the identification of best practices that merit a more widespread implementation across the extractive sector. In July 2017, the Commission launched an open call for input to support the development of guidance documents in the field of extractive waste management plans including on aspects related to the circular economy. This document should be completed in 2018 drawing notably on practices in Member States. It will be complementary to the Best Available Techniques reference document (BREF) on the management of extractive waste, which is currently being revised.

Related to the action on best practices in the field of extractive waste management plans, the Circular Economy Action Plan also covers an action on sharing of best practice for the recovery of CRMs from mining waste (and landfills). A number of ongoing Horizon 2020 projects are relevant to this action.

5.1.4. *Cooperation with advanced mining countries outside the EU*

As part of EU Raw Materials Diplomacy[71], the Commission organised in Brussels in 2014, 2015 and 2016 workshops with advanced mining countries[72] on best practices on mining policies and technologies. Each workshop contained one or two sessions

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[68] http://ec.europa.eu/environment/waste/studies/index.htm#extractive_waste

[69] Belgium, Bulgaria, Ireland and Sweden

[70] Austria, Croatia, Czech Republic, Estonia, Germany, Italy, Malta, Poland, Romania and Spain

[71] https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/international-aspects_en

[72] Australia, Brazil, Canada, Chile, Mexico, Peru, South Africa and USA

dedicated to mining waste management, increasingly focusing on the economic potential of recovery of (critical) raw materials from mining waste. These workshops allowed a regular exchange of experiences between the EU and advanced mining countries. In addition, in 2015, the Commission organised an international conference[73] for exchange of good practices on metal by-products recovery, addressing technology and policy challenges, including regarding the recovery of several CRMs as by-products.

5.1.5. *Best Practices*

- Systems-integrated material production: Taking optimal account of the "companionality" of metals, i.e. the production of many critical metals is dependent on the production of carrier (base) metals. The picture below summarises the chemical and physical linkages between metals and the set of metallurgical processes that has been developed to accommodate these linkages. Base metals which are potential sources of CRMs can be seen as part of a systems-integrated metal production approach. It applies to both mining and recycling.

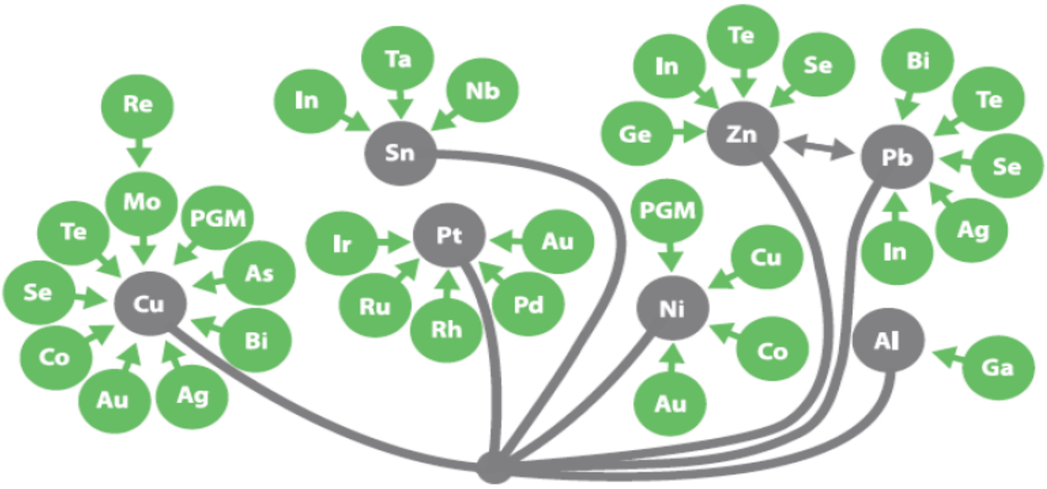

Figure 10: Sources of certain critical (and non-critical) raw materials (green) and their associated base metal (grey)[74]

- Developing a dedicated national (or regional) strategy, or guidance, for the reprocessing of extractive waste.[75]
- Benefiting from technological advancements, the Penouta mine in Spain re-started mining operations in 2011 processing extractive waste to extract tin, tantalum and niobium and other minerals obtained in co-production.
- The Horizon 2020 project SCALE[76] is developing a European scandium value chain through innovations which will allow the extraction of scandium from European bauxite residues.
- Improving the state of knowledge on extractive waste sites: the ongoing Horizon 2020 projects ProSUM and SMART GROUND are active in the area of data availability on CRMs in extractive wastes in view of a comprehensive pan-European

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[73] https://ec.europa.eu/growth/tools-databases/eip-raw-materials/en/content/international-conference-%E2%80%9Cexchange-good-practices-metal-products-recovery-technology-and

[74] Resnick Institute 2011

[75] European Commission (2017): Assessment of Member States' performance regarding the implementation of the Extractive Waste Directive

[76] http://scale-project.eu/

database on mining waste sites, which is currently missing.

5.1.6. *Possible further actions*

- Improve the knowledge base by organising and reinforcing pan-European data acquisition, collection, and management at all levels on extractive waste sites (both legacy and active ones), on the mineralogical and elemental composition of the waste.
- Support the development of tools to assess feasibility and benefits (economic, environmental safety, etc.) related to the recovery of CRMs from mining wastes.
- Further support the development of technologies to efficiently extract CRMs from primary ores and extractive wastes.

5.2. Landfills

Many of Europe's landfills, which total number is estimated to exceed 500,000[77] represent a potential source of CRMs that may be recovered either from disposed waste electronic equipment or from certain industrial wastes containing CRMs.

5.2.1. *Data and data sources*

Eurostat[78] provides yearly statistics about the flows of municipal solid waste disposed in landfills. These statistics show a trend of reduction of landfilled waste from 144 million tonnes in 1995 to 61 million tonnes (-58%) in 2015 in the EU, representing 26% of municipal waste. In addition, statistics on total waste shows that its landfilling rate in 2014 was 47%, while the landfilling rate of waste excluding major mineral wastes was 27%.

No systematic collection of data specific to CRMs ending up in landfills is carried out and, subsequently, no precise statistics are currently available. Only rough estimates of the flows and amount of CRMs ending up in landfills are presently possible, such as those provided in the MSA study[79], through two parameters:

- “Annual addition to stock in landfill” that quantifies the amount of the element that is annually added to landfill (in the EU), including processing waste, manufacturing waste, products at end of life and recycling waste; and
- “Stock in landfill” that quantifies the amount of the element in landfill (in the EU). For the calculation of the stock, the study generally considers the amount of material accumulated in landfill over the last 20 years as a maximum level.

The estimated amounts of CRMs annually sent to landfills and the estimated accumulation in landfill over the last 20 years in the EU are plotted in Figure 11. Quantities are indicative and are mostly derived from mass balances and expert assumptions. Moreover, CRMs accumulated in landfills have likely undergone chemical and physical changes, which means that their possible recovery must be carefully assessed.

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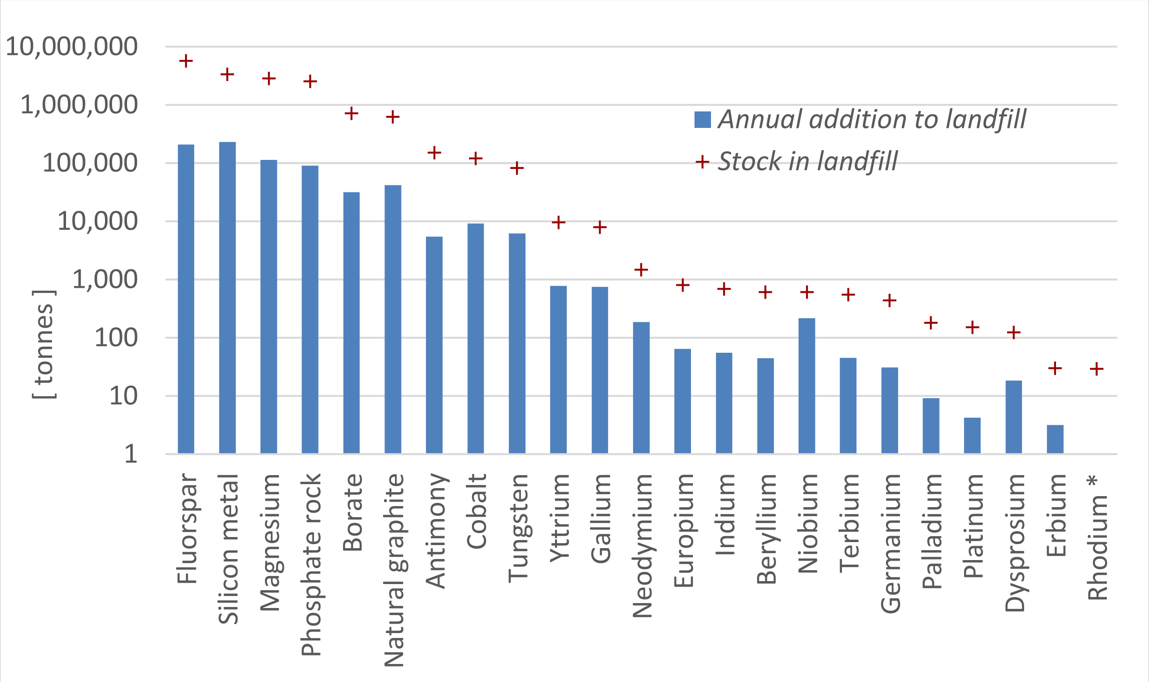
[77] https://www.eurelco.org/infographic

[78] http://ec.europa.eu/eurostat/statistics-explained/index.php/Municipal_waste_statistics

[79] https://ec.europa.eu/jrc/en/scientific-tool/msa



** Rhodium annual addition to landfill = 0.7 tonnes*

Figure 11: Amounts of CRMs as "Annual addition to stock in landfills in EU" and "Stock in landfill in EU" (JRC elaboration based on MSA study (2015))

A recent study[80] provided a first estimate of the concentration of CRMs in British landfills operating between 1980 and 2011 and receiving municipal, commercial and industrial waste. This study found that the overall concentration of CRMs in these landfills was about 380 mg/kg[81]. If these concentrations were generalised to the EU landfills, a rough estimated total content of for instance rare earth elements would be 470-520 thousand tonnes.[82] Larger amounts could be present considering also the landfills operating before 1980, but no detailed data are available on their composition.

The Horizon 2020 project SMART GROUND[83] fosters resource recovery in landfills (landfill mining) by improving the availability and accessibility of data and information on secondary raw materials present in landfills in the EU. The project will integrate all the data from existing databases and new information retrieved in a single EU databank.

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[80] Gutiérrez-Gutiérrez (2015), Rare earth elements and critical metal content of extracted landfilled material and potential recovery opportunities. Waste Management, (42).

[81] In particular, it was reported that the concentration of REEs (Sc, Y, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu) was 220 ±11 mg/kg, PGMs; concentration of PGMs (Pt, Pd, Ru) was 2,1 ±0,2 mg/kg; concentration of other metals (Li, Ln, Sb, Co) was 156 ±7 mg/kg. Concentration of other valuable metals (such as Cu, Al, Ag, Au) in such landfills was 6,6 ±0,7 g/kg.

[82] Estimations provided by the SMART GROUND project

[83] http://www.smart-ground.eu

Data sources

No	Name and link/ref.	Scope			Reference period / date of publ.	Language	Free / subscription	Comments
		Subsectors	CRMs	Geographic area				
1	Eurostat[84]	Municipal waste statistics		EU 28	1995-2015	English	yes	Data on municipal waste generated and treated in the EU. It includes statistics on waste landfilled.
2	Eurostat	Total waste statistics		EU 28	2004-2014	English	yes	Data on total waste generated and treated in the EU. It includes statistics on waste landfilled.
3	MSA study[85]	Various	CRMs (2014)	EU 28	2016 (updated every 3-5 years)	English	yes	Flows of materials landfilled estimated for 28 raw materials (including all the CRMs identified in the CRM study of 2014)
4	EURELCO[86]	Landfills	All	EU 28	2014-onward	English	yes	European network for enhanced landfill mining, including data collection and presentation
5	SMART GROUND[87]	Landfills	All	EU 28 (with focus on certain case-study countries)	2015-2018	English	yes	Data on secondary raw materials, including characterisation of landfills for CRMs

5.2.2. *Existing EU policies*

Rules are in place in the EU, such as Directives 2008/98/EC on waste[88] and 1999/31/EC on the landfill of waste[89], to ensure that environmental and human health risks posed by landfill operations are mitigated and subsequently eliminated. However, it should be noted that landfills or tipping sites no longer in operation as of the entry into force of the first EU Waste Framework Directive in 1977 are not subject to EU environmental and public health protection rules.

5.2.3. *Circular Economy Action Plan*

The Circular Economy Action Plan acknowledges that landfills could be a source for recovering critical raw materials. It contains an action on sharing of best practice for the recovery of CRMs from landfills (and mining waste). A number of ongoing EU-funded projects are relevant to this action.

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[84] http://ec.europa.eu/eurostat/statistics-explained/index.php/Municipal_waste_statistics

[85] https://ec.europa.eu/jrc/en/scientific-tool/msa

[86] https://www.eurelco.org/infographic

[87] http://www.smart-ground.eu/

[88] OJ L 312, 22.11.2008

[89] OJ L 182, 16.7.1999.

5.2.4. Best Practices

- EU network for landfill mining: The EURELCO[90] (European Enhanced Landfill Mining Consortium) is a Raw Material Commitment recognised by the European Innovation Partnership on Raw Materials. It supports technological, legal, social, economic, environmental and organisational innovation in the area of 'enhanced landfill mining' i.e. safe exploration, conditioning, excavation and integrated valorisation of (historic, present and/or future) landfilled waste as both materials - including CRMs - and energy.
- Investigation and characterisation of landfills in the EU e.g. through the on-going SMART GROUND Horizon 2020 project (see above).

5.2.5. Possible further actions

- Examine options for promoting the recovery of materials (and energy) from historic and present landfills under economically viable conditions.

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[90] http://www.eurelco.org/mission

5.3. Electrical and Electronic Equipment

5.3.1. *Data and data sources*

The electrical and electronic equipment (EEE) sector depends on a variety of CRMs including antimony, beryllium, cobalt, germanium, indium, platinum group metals (PGMs), natural graphite, rare earth elements (REEs), silicon metal, and tungsten (Figure 12).

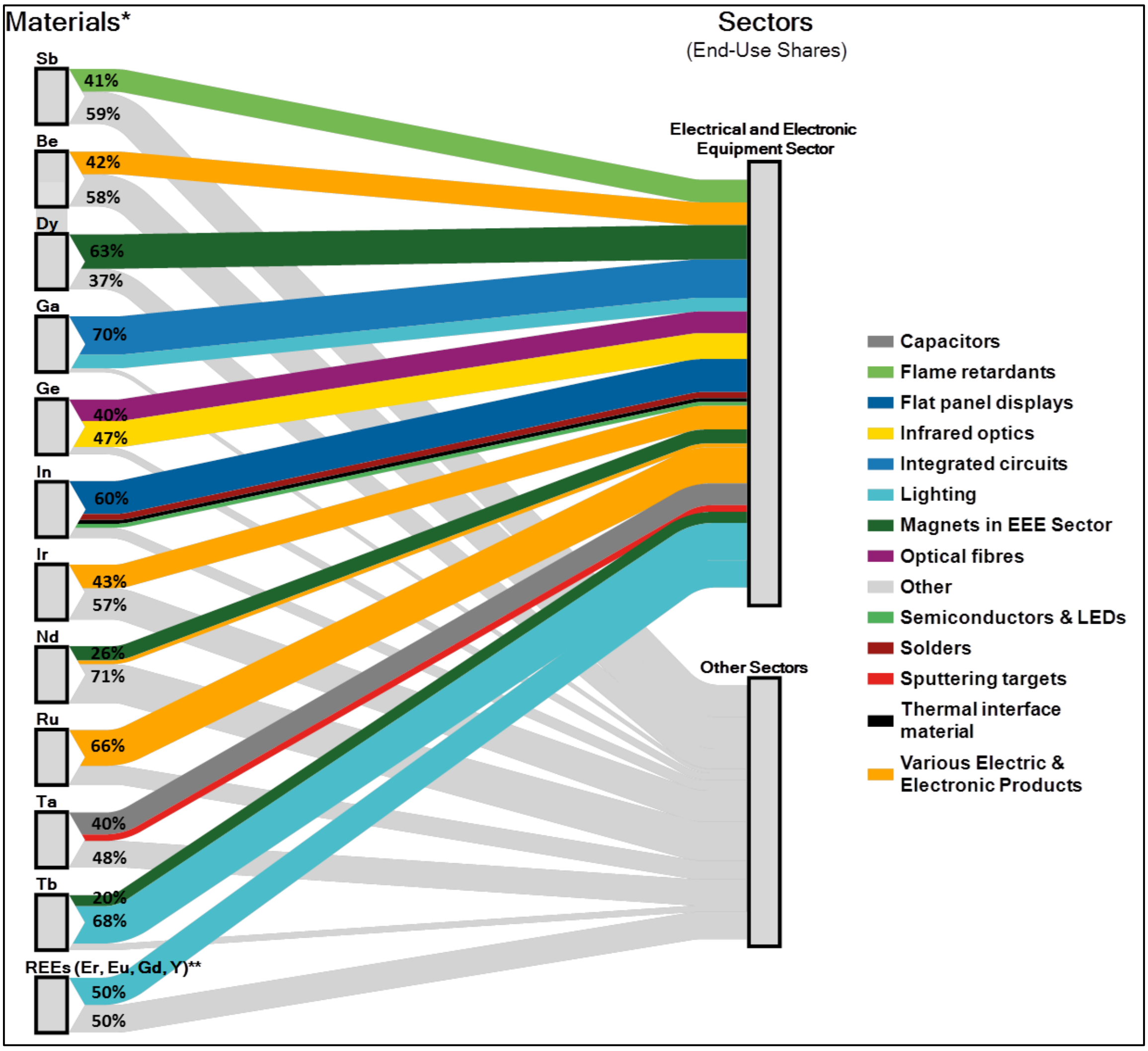

Figure 12: Share of CRMs used in the electric and electronic sector according to the 2017 CRM assessment[91]

* Only a subset of CRMs used in the EEE sector are included. Additional CRMs linked to the EEE sectors include Ce, Co, Fluorspar, Hf, He, La, Mn, Natural rubber, Pd, Pt, Pr, Rh, Sm, Si, W, and V.
**Average share for Er, Eu, Gd, and Y.

For example, gallium finds widespread use in integrated circuits and light emitting diodes (LEDs) for lighting. Other important product application associated with the EEE sector includes, e.g., magnets, flat screen displays, and optical fibres. Figure 12 also shows that the EEE sectors are the major user of gallium (95% of the element is used in

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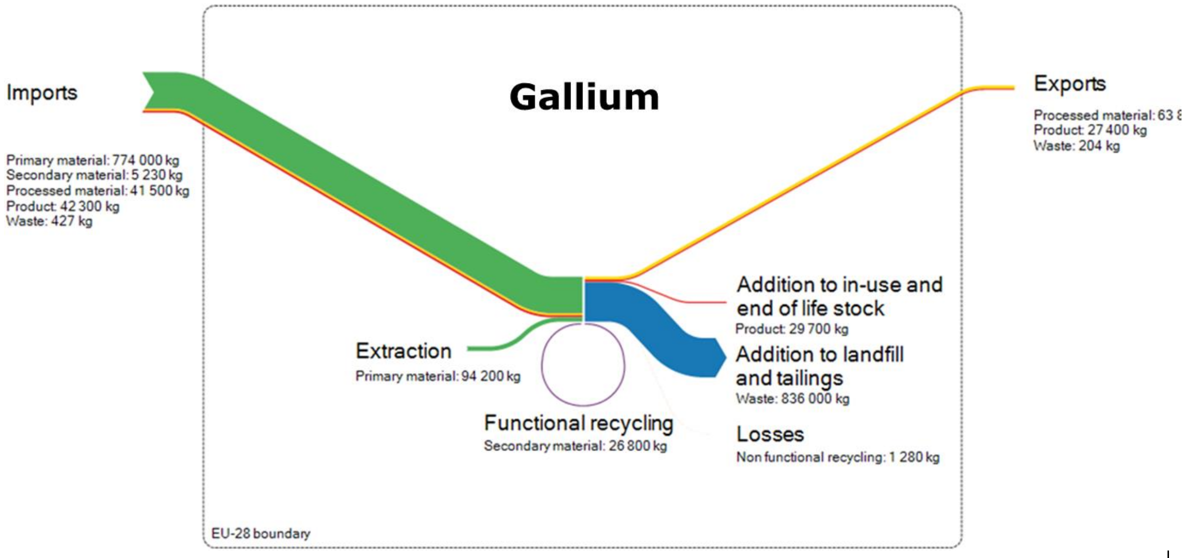
[91] JRC elaboration based on data from the 2017 EU criticality assessment. The EEE sector consists of two NACE sectors (C26 – Manufacture of computer, electronic and optical products and C27 – Manufacture of electrical equipment). The share of Sb in flame retardants used in the EEE sector is estimated at 96% (http://www.oakdenehollins.com/media/316/WRAP_01_316_IMT002_CRMs_in_the_UK_Summary_FINAL_0.pdf). The fraction of Nd, Pr, Dy, and Tb in magnets used in the EEE sector is based on a global average figure given in Du and Graedel. Global Rare Earth In-Use Stocks in NdFeB Permanent Magnets. Journal of Industrial Ecology 2011, 15 (6), 836–843.

the EEE sectors), germanium (87%), indium (81%), and several REEs (e.g., used in lighting applications).

Some flows of CRMs reach indirectly EEE, and these flows are not always captured by statistics. For example, 52% of the overall flow of antimony is used to produce flame retardant for plastics[92], afterwards used to manufacture EEE. Additional information of these flows is necessary to capture the final uses of CRMs. This implies that the relative relevance of EEE for certain CRMs can be even higher than shown in Figure 12.

For CRMs used predominantly in the EEE sectors (i.e., gallium, germanium, indium, and dysprosium (as an example of a heavy REE[93]), Figure 13 provides an indication of the amounts of secondary materials functionally recycled to contribute to EU demand in 2012 (see purple coloured Sankey line).

Figure 13: Simplified Sankey diagrams for materials used predominantly in the EEE sector: (a) Gallium (b) Germanium (c) Indium and (d) Dysprosium. Values for the EU-28 expressed in t/year for the year 2012 based on the 2015 MSA study[94]



(a)

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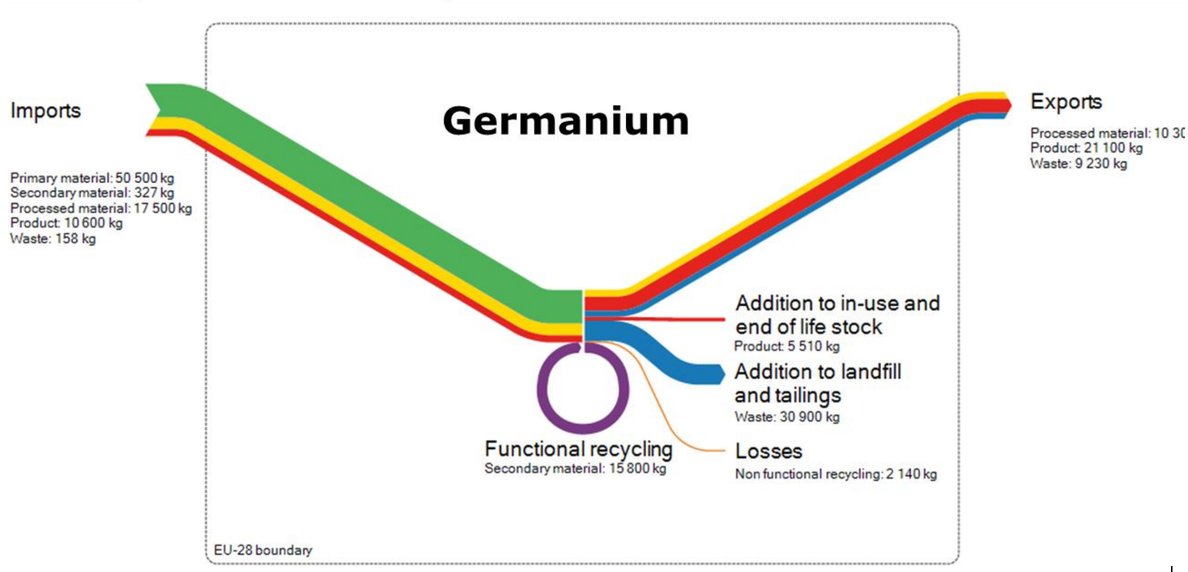
[92] Antimony is generally applied as a synergist (antimony trioxide) for brominated flame retardants used into EEE.

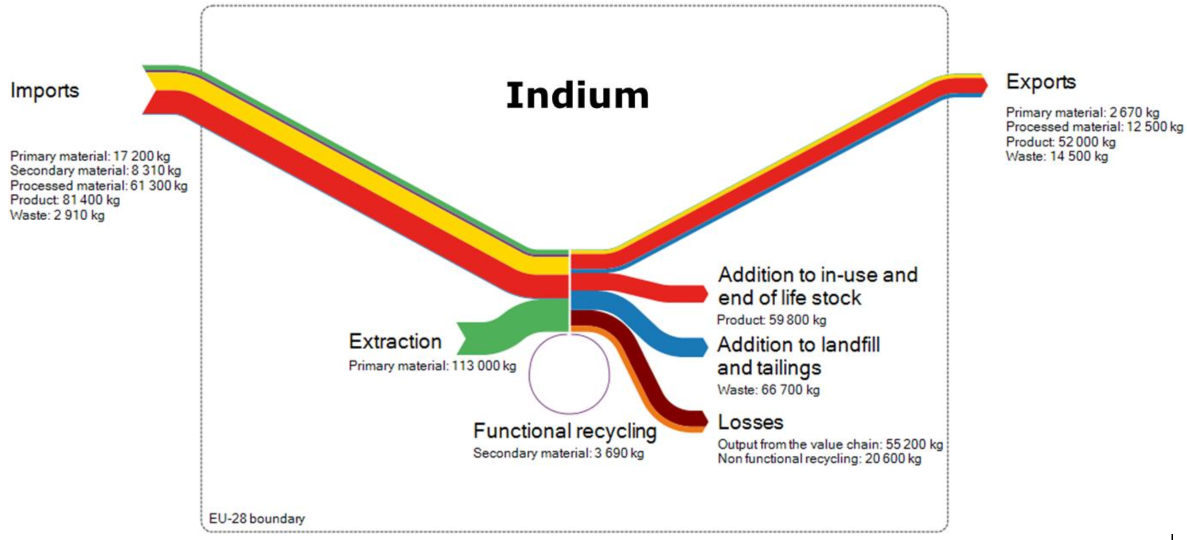
[93] Heavy rare earth elements are important constituents of tri-band phosphor lighting used for linear fluorescent tubes and compact fluorescent lamps, as well as CCFL LCD backlights for flat panel displays.

[94] https://ec.europa.eu/jrc/en/scientific-tool/msa

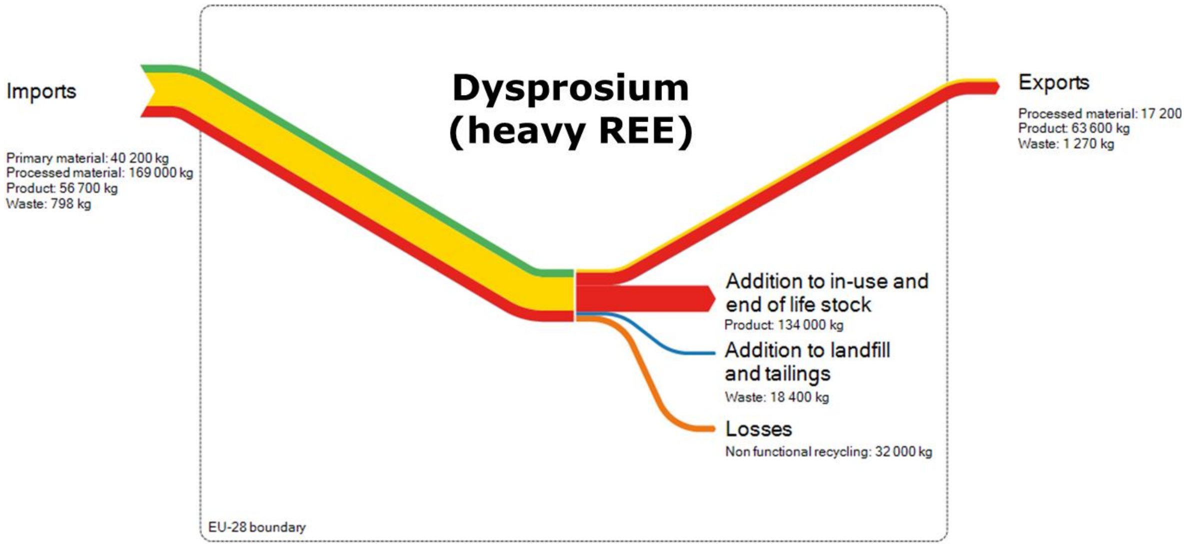


(b)

🟩 Primary material [t]
🟪 Secondary material [t]
🟨 Processed material [t]
🟥 Product [t]
🟦 Waste [t]
🟫 Output from the value chain [t]
⬜ In use dissipation [t]
🟧 Non functional recycling [t]



(c)



(d)

- 🟩 Primary material [t]
- 🟪 Secondary material [t]
- 🟨 Processed material [t]
- 🟥 Product [t]
- 🟦 Waste [t]
- 🟫 Output from the value chain [t]
- ⬜ In use dissipation [t]
- 🟧 Non functional recycling [t]

For example, Figure 13 shows that currently only a small fraction of CRMs remains inside Europe's socio-economic system through functional recycling. For dysprosium (one of the heavy REEs), functional recycling is not observed at all. The potential to improve recycling of materials depends on various factors such as recycling infrastructure, market prices, possibility to disassemble products, and the amount of material becoming available from products reaching their end-of-life. In some cases, material flows are going to stock (e.g. when used in durable products) and they are not available for recycling for several years. This, however, is often the result of a continuous service of the materials to the society i.e. maintaining value within the economy, in line with the circular economy concept.

Lifetime of CRMs in EEE largely depends on the type of application and the end-use product. For example, lifetimes of REEs can vary from a few years (or even months) for lamps, up to decades in high efficiency motors. It is not possible either to generalise on the ease of disassembly (and hence of repair and re-use) of certain parts containing CRMs, since this depends on the type of product and even its brand. It is observed that the trend of miniaturisation of electronics is generally making disassembly of components increasingly challenging.

At the same time, the recycling of CRMs contained in EEE largely depends on the type of application and on the value of the raw materials. For example, precious metals in electronics (e.g. PGMs in printed circuit boards) are generally separated and recycled because this is economically viable[95]. On the contrary, the recycling of materials such as

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[95] http://www.umicore.com/en/about/elements/

gallium, germanium, indium, silicon metal, and REEs is more challenging because of their disperse use in products[96].

Few data are available about the reuse of EEE. Reuse of EEE is generally not much established in the EU, except for some durable household products, e.g., washing machines and dishwashers, for which the reuse rate in certain EU countries can amount to 1% of the flow[97].

The ProSUM EU Urban Mine Knowledge Data Platform provides data on stocks and flows of secondary raw materials arising from different WEEE such as end-of-life screens, including end-of-life Cathode Ray Tube (CRT) TVs and monitors, Liquid Crystal Display (LCD) based TVs and monitors, laptops, and tablets[98]. The project has estimated the content of screens placed on the market and screen waste over time (see Figures 14 and 15). This includes the content of precious metals such as gold (Au) and silver (Ag) but also CRMs such as indium (In), neodymium (Nd) and palladium (Pd).

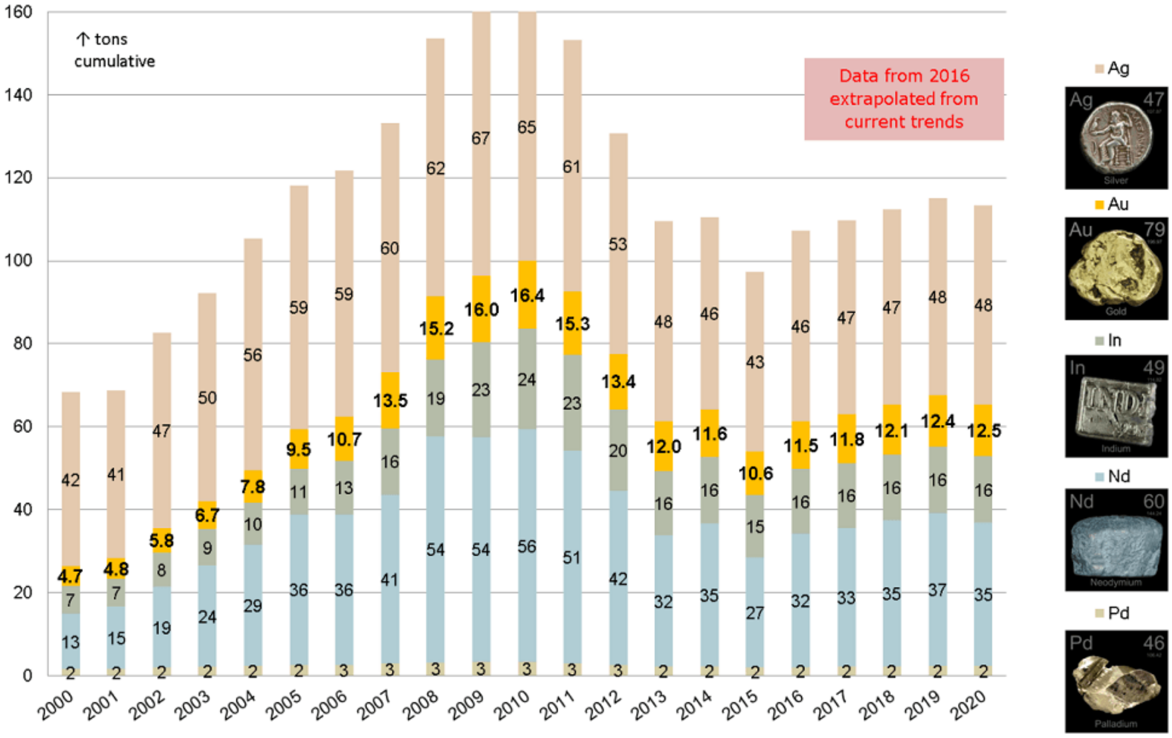

Figure 14: Selected precious metals and CRMs in screens placed on market 2000-2020, in tonnes (source: ProSUM project)

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[96] http://bookshop.europa.eu/en/feasibility-study-for-setting-up-reference-values-to-support-the-calculation-of-recyclability-recoverability-rates-of-electr-on-ic-products-pbLBNA27922/

[97] http://publications.jrc.ec.europa.eu/repository/handle/JRC102632

[98] More detailed information can be found on http://rmis.jrc.ec.europa.eu/?page=contributions-of-h2020-projects-236032

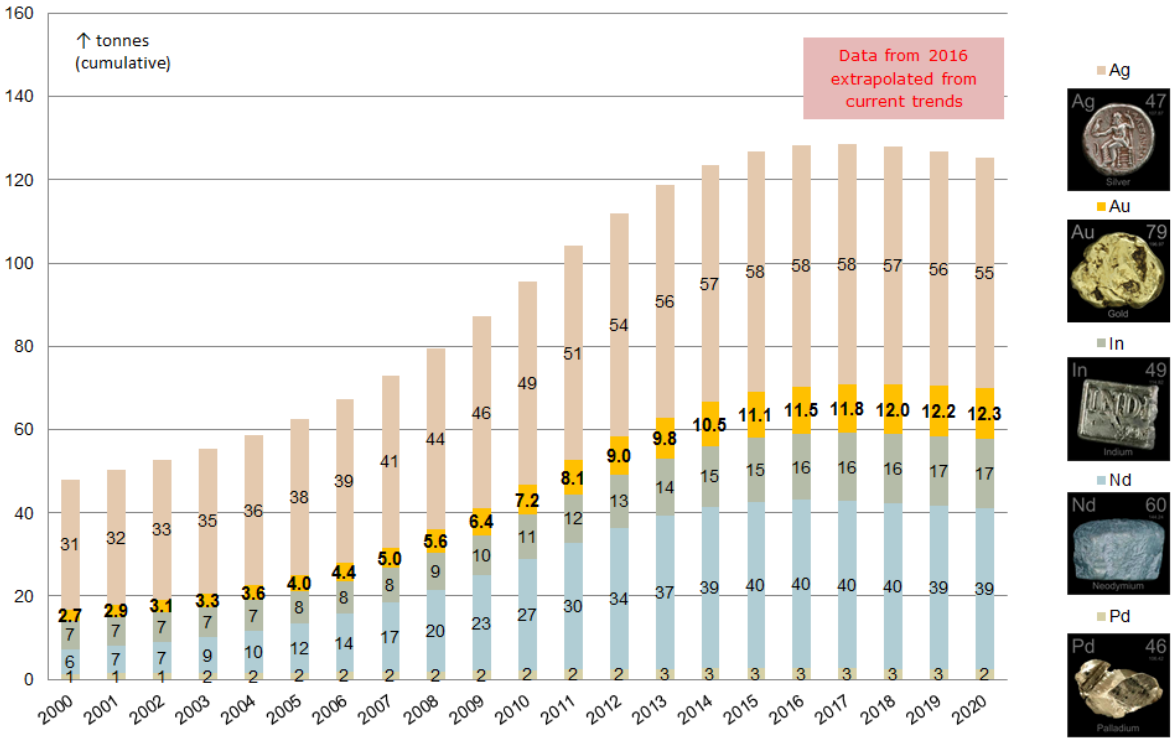

Figure 15: Selected precious metal and CRM content estimated in screen waste generated in the EU 2000 -2020, in tonnes (source: ProSUM project)

Data sources

No	Name and link/ref.	Scope			Reference period / date of publ.	Language	Free / subscription	Comments
		Subsectors	CRMs	Geographic area				
1	Eurostat[99]	WEEE	-	EU 28	2005-2014	English, German, French	Free	Data on WEEE collected and treated by Member States
2	ProSUM[100]	WEEE	All	EU 28	2015-	English	Free	Data on stocks and flows of secondary raw materials
3	Ecodesign preparatory study on enterprise servers[101]	Enterprise servers	All	EU 27	2014	English	Free	Example of preparatory study investigating the relevance of certain CRMs for the product group in question[102]
4	Review of Ecodesign preparatory study on fan[103]	Fans	Rare Earths	EU 27	2015	English	Free	Example of preparatory study investigating the relevance of rare earths for the product group in

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[99] http://ec.europa.eu/eurostat/web/waste/key-waste-streams/weee

[100] http://www.prosumproject.eu/

[101] https://bookshop.europa.eu/en/ecodesign-preparatory-study-on-enterprise-servers-and-data-equipment-pbET0415685/;pgid=GSPefJMEtXBSR0dT6jbGakZD0000SnCBUHBt;sid=dGYfUdVvKhofVY0Th7OB9rdKc7UZgnesCDY=

[102] See also the JRC study on material efficiency aspects of servers: https://bookshop.europa.eu/en/environmental-footprint-and-material-efficiency-support-for-product-policy-pbLBNA27467/

[103] http://www.eceee.org/static/media/uploads/site-2/ecodesign/final_report_fan_review_-_16_mar_2015.pdf

								question
5	Recovery of rare earths from electronic waste: an opportunity for high-tech SMEs. Study for the ITRE Committee IP/A/ITRE/2014-09.	EEE	REEs	EU28	2014	English	Free	

5.3.2. Existing EU policies

The Ecodesign Directive[104] addresses the potential negative impact that energy-related products can have on the environment. It does so by 'pushing' the market towards more energy efficient products as the worst performing ones are banned from the market. This Directive is complemented by the Energy Labelling Directive[105], which 'pulls' the market towards more energy (and resource) efficient products by informing consumers about their energy performance through the well-recognised and understood EU energy label.

The Ecodesign Directive provides an overall framework, while specific requirements are put in place for different groups of products that have, during their use, an impact on the energy consumption. These requirements are set after analysing the impact the products can have on the environment during their production, use and disposal or recycling.

The Ecodesign Working Plan 2016-2019[106], adopted as part of the Clean Energy for All Europeans package, sets out to give more support to measures seeking to improve resource efficiency, reparability, recyclability and durability. See Annex II for examples of CRMs discussed within Ecodesign preparatory studies.

The WEEE Directive 2012/19/EU has as its objective to contribute to sustainable production and consumption of EEE through, as a first priority, the prevention of waste and, in addition, by the preparation for re-use, recycling and other forms of recovery of waste of EEE, so as to reduce the disposal of waste and to contribute to the efficient use of resources and the retrieval of valuable secondary raw materials contained in EEE.

The WEEE Directive sets collection targets to be met over time. Until 2015 the target of 4 kilograms per inhabitant from private households applied, while a target of 45% of the average weight of EEE placed on the market in the three preceding years applies from 2016. From 2019, a target of 65% of the average weight of EEE placed on the market in the three preceding years, or 85% of WEEE generated in the year of reference, applies.

The WEEE Directive also requires that all separately collected WEEE undergoes proper treatment in order to avoid losses of valuable secondary raw materials. To this end, it sets recovery targets which are applicable per EEE category as set out in Annex V to the Directive. Annex VII to the Directive lays down minimum treatment requirements.

To assist relevant operators in fulfilling the requirements of the WEEE Directive, the Commission requested the European Standardisation Organisations to develop non-binding European standards for the treatment, including recovery, recycling and preparing for reuse of WEEE, reflecting the state of the art. The standards[107] have been largely finalised by CENELEC.

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[104] Directive 2009/125/EC

[105] Directive 2010/30/EU

[106] COM(2016) 773 final

[107] http://ec.europa.eu/environment/waste/weee/standards_en.htm

In order to support Member States in reaching the targets and the full implementation on the ground of the Directive, the Commission has initiated a targeted compliance promotion initiative, starting with assessing the implementation in Member States. Critical factors and obstacles to reaching the targets as well as good practices are being identified, to enable Member States to learn from each other and for further developing WEEE policies.

5.3.3. *Circular Economy Action Plan*

Additional emphasis is to be put on circular economy aspects in future product requirements under the Ecodesign Directive. In 2016, standardisation work was started within CEN/CENELEC following a request[108] by the Commission. The work includes the development of a general method to declare the use of CRMs in energy-related products. The results of the standardisation work are expected by March 2019.

To facilitate preparation for reuse and the environmentally sound treatment of WEEE, supporting the requirement in the WEEE Directive[109], the Commission initiated a dialogue between manufacturers of EEE and re-use operators and recyclers of WEEE with the aim to improve the exchange of information needed for preparation for reuse and treatment of WEEE. Following a first workshop in 2015, European associations representing the parties concerned are engaged in discussions about how to further operationalise these requirements, specifying information needs and communication channels etc. Initially, the focus of these efforts lies on information needed for the environmentally sound treatment of WEEE as far as dangerous substances and mixtures are concerned, but the scope should be broadened at a later stage to also cover information that will foster the preparation for reuse of WEEE (components) and the recycling of CRMs, and be aligned with the above-mentioned standardisation work.

The Action Plan, with a view to fostering increased recycling of CRMs, also includes the development of European standards for material-efficient recycling of complex end-of-life products such as WEEE. The Horizon 2020 project SCRREEN (see Section 3.4) is carrying out preparatory work on WEEE to this end, and a request from the Commission to the European Standardisation Organisations is underway.

As pointed out in the Action Plan, in order to raise levels of high-quality recycling, improvements are needed in waste collection and sorting. A new Horizon 2020 funded project called COLLECTORS[110] will map different WEEE collection systems in Europe, gain insight into the overall performance of systems and support decision-makers in shifting to better-performing systems via capacity-building and guidelines.

Finally, in order to foster high-quality recycling in the EU and elsewhere, the Action Plan sets out to promote voluntary certification of treatment facilities for certain key types of waste including WEEE. The Commission has launched a call for proposals under Horizon 2020 to this effect.[111]

5.3.4. *Best Practices*

- Using the Ecodesign Directive to improve the design of EEE so as to increase the recycling of CRMs. Several eco-design regulations are asking manufacturers to

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[108] M/543, http://ec.europa.eu/growth/tools-databases/mandates/index.cfm?fuseaction=search.detail&id=564

[109] Article 15 of the WEEE Directive requires that producers provide information on different EEE components and materials, as well as the location of dangerous substances and mixtures in EEE which shall be made available to operators carrying out preparation for re-use and/or treatment operations.

[110] https://www.innovationplace.eu/project/collectors-waste-collection-systems-assessed-and-good-practices-identified/954

[111] https://ec.europa.eu/research/participants/portal/desktop/en/opportunities/h2020/topics/ce-sc5-08-2018-2019-2020.html

provide technical documentation of "*information relevant for disassembly, recycling or disposal at end-of-life*". More specifically, the regulation on ventilation units[112] requires "*detailed instructions (...) for the manual disassembly of permanent magnet motors, and of electronics parts*" that generally contain significant amounts of CRMs (in particular REEs). Several preparatory studies are addressing the use of CRMs and circular economy aspects, e.g. those on electronic displays or enterprise servers (see Annex II).

- Supporting the development of innovative recycling technologies for CRMs. The Commission has funded several research projects concerning the development of innovative solutions for the recycling of CRMs from EEE. For example, the RECLAIM project[113] led to the design and construction of an innovative plant for the recycling of yttrium and europium from spent fluorescent lamp powders. (See Section 3.6 for examples of on-going projects.)

5.3.5. Possible further actions

- Several recent preparatory studies under the Ecodesign Directive have come up with proposals of requirements to ensure an easier extraction at end-of-life of key components containing CRMs or proposals for declaring the content of some CRMs.
- Further explore with stakeholders the potential of new satellite technologies to better detect and tackle e-waste crime.

See also the Technological Roadmap to Near Zero Waste in WEEE[114] of the Horizon 2020 project NEW_InnoNet.

5.4 Batteries

(This section also covers to a certain extent batteries used in the automotive sector. For more information on such batteries, see Section 5.5.)

5.4.1 Data and data sources

There are three types of batteries: portable, industrial and automotive batteries. In the last decades, new battery chemistries have appeared on the market due to the development of new applications (e.g. electric vehicles, e-bikes). Depending on the battery chemistry, the main CRMs embedded in waste batteries are antimony, cobalt, natural graphite, indium and some rare earth elements (see Figures 16 and 17). Antimony is mainly use for lead-acid batteries, and its use has declined due to new battery technologies.[115] In contrast, in recent years the battery market has seen a relative increase in the amount of cobalt: from 25% of global end uses of cobalt in 2005 to 44% in 2015.[116] This is mainly related to specific Li-ion chemistries (e.g. Li-NMC suitable for new applications, see Figure 16). Concerning natural graphite, almost 10% of worldwide uses of graphite in 2010 was for the batteries sector.[117,118] In fact, graphite is widely used in several rechargeable and non-

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[112] Commission Regulation (EU) No 1253/2014. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32014R1253

[113] http://www.re-claim.eu/

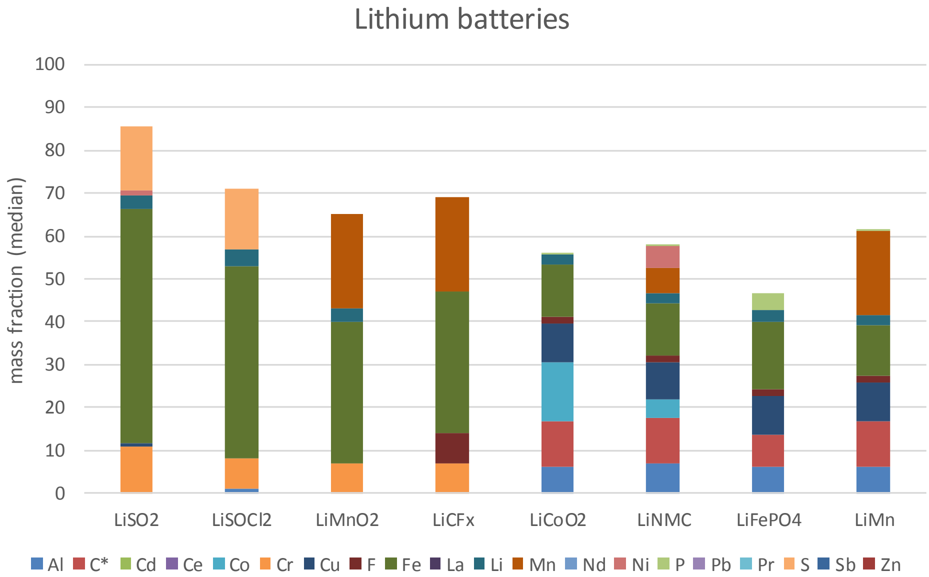
[114] http://www.newinnonet.eu/ReportsList.aspx

[115] EC, 2015. "Report on Critical Raw Materials for the EU critical raw materials profiles", available at http://ec.europa.eu/DocsRoom/documents/11911/attachments/1/translations/en/renditions/native

[116] 2017 CRM assessment

[117] EC, 2015. "Report on Critical Raw Materials for the EU critical raw materials profiles", available at http://ec.europa.eu/DocsRoom/documents/11911/attachments/1/translations/en/renditions/native

rechargeable batteries (both portable and industrial) as anode, for example in the quickly growing Li-ion battery market (see Figure 16).[119] From 2010 to 2017, alkaline batteries accounted for about 5% of indium consumption.[120] Finally, among rare earth elements, 10% of the worldwide lanthanum and 6% of cerium are used for NiMH batteries.[121]



* Graphite carbon

Figure 16: Elements embedded in Li-ion batteries according to specific chemistries (source: ProSUM project)

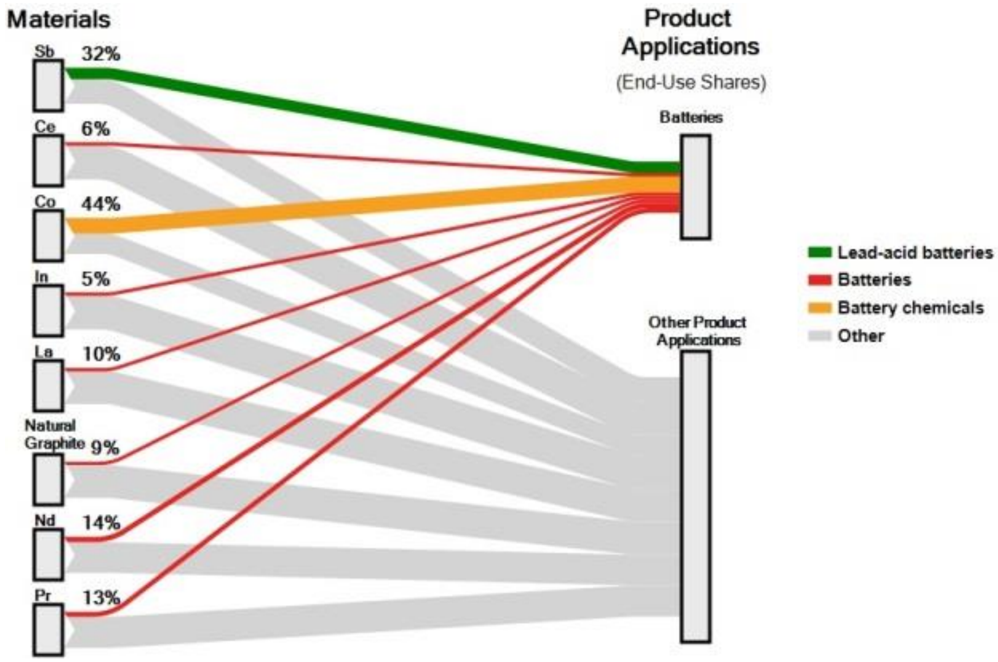


Figure 17: Flow of CRMs into battery applications according to the 2017 CRM assessment

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[118] Labie R. et al. (2015). "Recuperation of critical metals in Flanders: Scan of possible short term opportunities to increase recycling", available at https://steunpuntsumma.be/nl/publicaties/recuperation-of-critical-metals-in.pdf

[119] EC, 2015. "Report on Critical Raw Materials for the EU critical raw materials profiles", available at http://ec.europa.eu/DocsRoom/documents/11911/attachments/1/translations/en/renditions/native

[120] Indium Corporation (2013), The Indium Market. 2017 CRM assessment

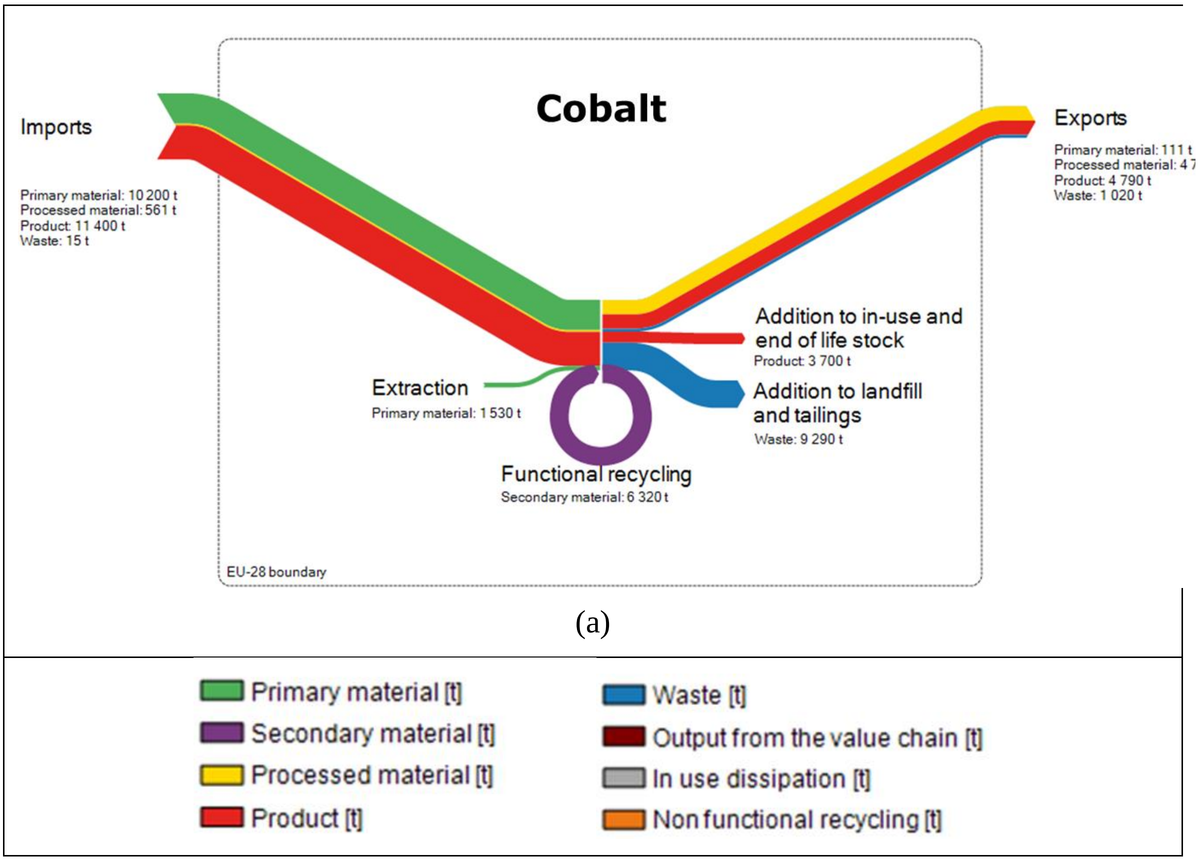
[121] 2017 CRM assessment

Actual collection rates of waste batteries depend on the battery technology/type (e.g. rechargeable/non-rechargeable batteries, Lithium/Ni-Cd batteries), on the lifetime of batteries, and on the end-use behaviour. For automotive lead-acid batteries, the collection and the recycling rates are much higher than for other batteries.[122]

Material produced from battery recycling can be used for the battery industry (e.g. cobalt) or steel and other industries, depending on the quality of the recycled material.

Recycling of cobalt mainly occurs thanks to the lower costs of the recovered cobalt compared to cobalt extraction from ores.[123] Recycling of graphite, on the other hand, is quite limited. In the recycling process of batteries, graphite is usually lost in the recovery processes. However, in hydrometallurgical processes, the recovery of graphite is possible.[124,125] Finally, the end-of-life recycling rates for lanthanum and cerium are below 1%.[126]

Figure 18: Simplified Sankey diagrams for materials used predominantly in the battery sector: (a) cobalt and (b) natural graphite. Values for the EU-28 expressed in t/year for the year 2012 based on the 2015 MSA study[127]



(a)

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[122] IHS Consulting, 2014. "The availability of automotive lead-based batteries for recycling in the EU", available at www.eurobat.org/sites/default/files/ihs_eurobat_report_lead_lores_final.pdf

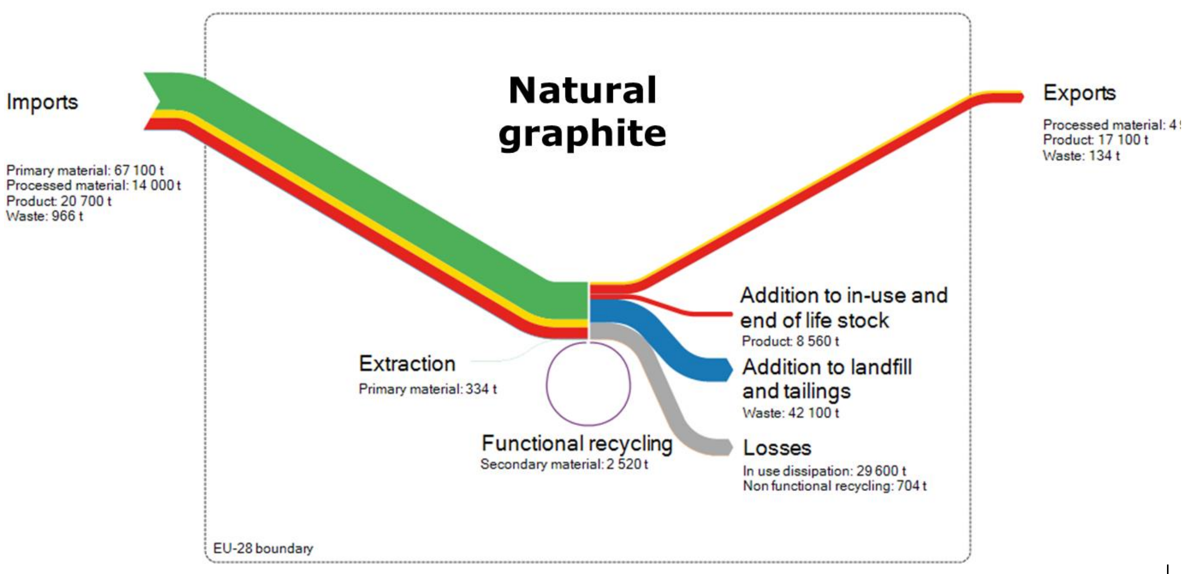
[123] EC, 2015. "Report on Critical Raw Materials for the EU critical raw materials profiles", available at http://ec.europa.eu/DocsRoom/documents/11911/attachments/1/translations/en/renditions/native

[124] EC, 2015. "Report on Critical Raw Materials for the EU critical raw materials profiles", available at http://ec.europa.eu/DocsRoom/documents/11911/attachments/1/translations/en/renditions/native

[125] Moradi, B. & Botte, G.G. J Appl Electrochem (2016) 46: 123. http://link.springer.com/article/10.1007/s10800-015-0914-0

[126] EC, 2015. "Report on Critical Raw Materials for the EU critical raw materials profiles", available at http://ec.europa.eu/DocsRoom/documents/11911/attachments/1/translations/en/renditions/native

[127] https://ec.europa.eu/jrc/en/scientific-tool/msa



(b)

🟩 Primary material [t]
🟪 Secondary material [t]
🟨 Processed material [t]
🟥 Product [t]
🟦 Waste [t]
🟫 Output from the value chain [t]
⬜ In use dissipation [t]
🟧 Non functional recycling [t]

Among the waste batteries flows, it is worth noting that the export flow of waste batteries to non-EU Member States is low; on the contrary, there is significant movement of waste batteries and accumulators between Member States.[128] However, batteries contained in EEE, especially rechargeable portable batteries, can enter in a second hand market outside of Europe.[129] Together with these waste flows, un-removed batteries from (W)EEE or batteries removed from WEEE but treated without recording their treatment contribute to increasing the data uncertainty.[130]

Data sources

No	Name and link/ref.	Scope			Reference period / date of publ.	Language	Free / subscription	Comments
		Subsectors	CRMs	Geographic area				
1	Eurostat[131]	"Lead batteries", "Ni-Cd batteries", "Other batteries and accumulators"	No specific data on CRMs	Europe	2009-2015	English	Free	Data about recycling of batteries and accumulators

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[128] Tsiarta et al., 2015, "Final Implementation Report for the Directive 2006/66/EC on Batteries and Accumulators", available at http://ec.europa.eu/environment/waste/batteries/studies.htm

[129] EPBA, 2015 "The collection of waste portable batteries in Europe in view of the achievability of the collection targets set by Batteries Directive 2006/66/EC", available at http://www.epbaeurope.net/documents/Reportontheportablebatterycollectionrates-UpdateDec-15-Exerpt.pdf

[130] EPBA, 2015

[131] http://ec.europa.eu/eurostat/data/database?node_code=env_wasbat

2	Eurostat[132]	Portable and batteries accumulators	No specific data on CRMs	Europe	2009-2015	English	Free	Data about sales and collection of portable batteries and accumulators
3	ProSUM[133]	Batteries	All	EU 28	2015-	English	Free	Data on stocks and flows of secondary raw materials
4	EPBA (European Portable Batteries Association)[134]	Portable batteries	No specific data on CRMs	Europe	1995 - 2014	English	Free	Data on collection rates in EU countries
5	Recharge (European Association for Advanced Rechargeable Batteries)[135]	Li-ion batteries	No specific data on CRMs	Europe	2006-2013	English	Free	Data about collection rates of portable batteries in Europe
6	EUROBAT (European Automotive and Industrial Battery Manufacturers) [136]	Automotive and industrial batteries	Antimony and cobalt	Europe	2011-2015	English	Free	Data about battery market volume. Considerations of antimony and cobalt in the report "Resource Availability of Metals used in Batteries for Automotive Applications".
7	EUCOBAT (European association of national collection schemes for batteries)[137]	Portable batteries	No specific data on CRMs	Europe	2000-2012	English	Free	Data about the collection rate of portable batteries
8	EBRA European Battery Recycling Association[138]	Batteries' recycling	No specific data on CRMs	Europe	2009-2012	English	Free	Statistics about battery recycling
9	Darton Commodities. 2016. Cobalt market review, 2015-2016[139]	All sectors with specific data on Li-ion batteries	Cobalt	Worldwide	2015-2016	English	Subscription	
10	Roskill: Natural and Synthetic Graphite Market Outlook (2015) [140]	All sectors with specific data on Li-ion batteries	Graphite	Worldwide	2015-2020	English	Free	

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[132] http://ec.europa.eu/eurostat/data/database?node_code=env_waspb

[133] http://www.prosumproject.eu/

[134] http://www.epbaeurope.net/pub_technicalSupport.html

[135] http://www.rechargebatteries.org/contribution-of-advanced-rechargeable-batteries-to-the-eu-agenda-and-initiatives-on-climate-energy-raw-materials-resource-efficienc/

[136] http://eurobat.org/brochures-reports, https://eurobat.org/statistics

[137] http://www.eucobat.eu/downloads

[138] http://www.ebra-recycling.org/releases

[139] http://www.dartoncommodities.co.uk/cobalt/

[140] https://roskill.com/market-report/natural-synthetic-graphite/

5.4.2 *Existing EU policies*

The Batteries Directive (2006/66/EC) establishes obligations for Member States to maximise the collection of waste batteries and accumulators, and to ensure that all collected batteries undergo proper treatment and recycling. To this end, the Directive defines targets for collection rates and for recycling efficiencies. The Directive is expected to achieve economies of scale in collection and recycling, as well as optimal resource saving.

In 2015 only 9 Member States had reached the 45% target for collection of portable batteries established for 2016. However, recycling processes in most countries achieved the minimum levels of recycling efficiencies set by the Directive for lead, nickel-cadmium and other types of batteries.

The Directive requires the Commission to review the impact of its provisions on the environment and internal market as well as to evaluate some particular aspects, in relation to heavy metals, targets and recycling requirements. The Commission has launched an evaluation process intended to assess whether the Directive is delivering its objectives, considering also whether new uses of batteries and the new technologies and chemistries developed since its adoption in 2006 are duly addressed. Likewise, the coherence between the provision of the Directive and EU policies on Circular Economy and raw materials is being assessed.

As announced in the renewed EU Industrial Policy Strategy[141], the Commission proposed a second Mobility Package on 8 November 2017[142] following the 2016 Strategy for low emission mobility and the spring 2017 first Mobility Package[143]. The November 2017 package includes strengthened post-2020/2021 carbon dioxide standards for cars and vans and an Alternative Fuels Infrastructure Action Plan to support the deployment of an EU backbone charging infrastructure. Technologies based on batteries make a crucial contribution to the achievement of the objectives of these plans. How to foster better supply conditions for several CRMs is an important consideration in this context.

5.4.3 *Circular Economy Action Plan*

The Action Plan, with a view to fostering increased recycling of CRMs, includes the development of European standards for material-efficient recycling of complex end-of-life products such as batteries. A request from the Commission to the European Standardisation Organisations is underway.

5.4.4 *Best Practices*

- Improving the efficiency in the recycling of CRMs in batteries. In Europe, several recyclers have invested in research projects in order to increase the recycling efficiency including for CRMs.[144,145,146]
- *Projects for Policy* (P4P) is an initiative aimed at using research and innovation project results to support policy making. Several batteries projects[147] addressed

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[141] COM(2017) 479

[142] https://ec.europa.eu/transport/modes/road/news/2017-11-08-driving-clean-mobility_en

[143] COM(2016) 501; COM(2017) 283

[144] http://www.recupyl.com/121-20-31-lithium-polymer-battery.html, http://recupyl.com/44-used-batteries-recycling-plant.html

[145] http://www.akkuser.fi/en/news.htm

[146] http://www.accurec.de/

[147] BATTERIES2020, MARS EV, EVERLASTING

issues such as life-time, re-use and recycling and contributed to policy recommendations.[148]

5.4.5 *Possible further actions*

- Promote suitable design for disassembly of WEEE so that batteries can be readily removed (see Section 5.3.5).

Further options are to be identified and assessed as part of the on-going evaluation of the Batteries Directive.

5.5 Automotive sector

5.5.1 *Data and data sources*

In the automotive sector, including conventional (combustion engine vehicles), hybrid (HEVs) and electric vehicles (EVs), several vehicle components contain CRMs. Some examples are graphite (in brake linings, exhaust systems, motors, clutch materials, gaskets and batteries), cobalt (in lithium-ion batteries especially for EVs), Platinum Group Metals (palladium, platinum and rhodium in auto-catalysts and particulate filters), niobium (as an alloying agent in high-strength steel and nickel alloys used in the body structure, engine system and structural components[149]) and Rare Earth Elements (in permanent magnets, auto-catalysts, filters and additives).[150,151,152]

About 14% of worldwide uses of graphite in 2011 refer to automotive parts.[153] In 2012, the share of EU demand of palladium for petrol engines was 69%, 70% of platinum was used for light duty diesel engines, and 80% rhodium for 3-way catalytic converters used to reduce tailpipe emissions from vehicles.[154] With respect to niobium, in 2012 44% of the EU demand was intended to the automotive sector.[155] Among the REEs, neodymium, praseodymium and to a lesser extent dysprosium and terbium are used in large high performance neodymium-iron-boron magnets for HEVs and EVs electric motors. These are also used in small electric motors and electronic sensors for the standard automotive industry including starter motors, brake systems, seat adjusters and car stereo speakers.[156] Moreover, lanthanum and cerium are embedded for example in nickel metal hydride (NiMH) batteries used in HEVs designs. Cerium is additionally used in auto-catalysts, which accounted for 35% of consumption in 2013.[157]

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[148] EC, 2017, "BATTERIES - A major opportunity for a sustainable society", https://ec.europa.eu/info/sites/info/files/batteries_p4p-report_2017.pdf

[149] Chalmers, 2013. “The Use of Potentially Critical Materials in Passenger Cars”, http://publications.lib.chalmers.se/records/fulltext/162842.pdf

[150] EC, 2015. “Report on Critical Raw Materials for the EU critical raw materials profiles”, http://ec.europa.eu/DocsRoom/documents/11911/attachments/1/translations/en/renditions/native

[151] http://www.criticalrawmaterials.eu/wp-content/uploads/CRM_InnoNet_transport-SCA_140514.pdf

[152] Roskill (2015). “Natural and Synthetic Graphite Market Outlook” and “Rare Earths Market Outlook to 2020”, https://roskill.com/market-reports/

[153] EC, 2015. “Report on Critical Raw Materials for the EU critical raw materials profiles”, http://ec.europa.eu/DocsRoom/documents/11911/attachments/1/translations/en/renditions/native

[154] EC, 2015. “Report on Critical Raw Materials for the EU critical raw materials profiles”, http://ec.europa.eu/DocsRoom/documents/11911/attachments/1/translations/en/renditions/native

[155] https://ec.europa.eu/jrc/en/scientific-tool/msa

[156] Roskill (2015). Rare Earths Market Outlook to 2020, 15th edition 2015

[157] Roskill (2015) . Rare Earths Market Outlook to 2020, 15th edition 2015

Although the internal combustion engine is likely to remain dominant in the short and medium term, the market for HEVs and EVs is expected to experience significant and rapid growth over the coming decades. The CRMs embedded in vehicles are expected to increase proportionally. Cobalt, graphite, and rare earths employed in Li-ion batteries and electric motors are among the most targeted by increasing EVs demand (Figure 19).

Lithium-ion is the reference technology for EV batteries. Many different Li-ion chemistries are currently available[158] and are being tested to improve the performance and lower the battery costs. For example, in recent years Li-ion chemistries have shifted in favour of lower cobalt compositions. Natural graphite in turn is the reference anode material. In comparison to available alternatives, natural graphite had a market share of 64 % in 2014.[159]

Levels attained by the EV market in the EU in 2015 created a demand for batteries of 510 t and 8330 t for cobalt and graphite, respectively.[160] With regards to the rare earths for electric traction motors, in 2015, new EV's sold in the EU used about 50 t of neodymium, 16 t of praseodymium and 16 t of dysprosium while the demand for HEVs was around 33 t of neodymium, 11t of dysprosium and 11 t of praseodymium.[161]

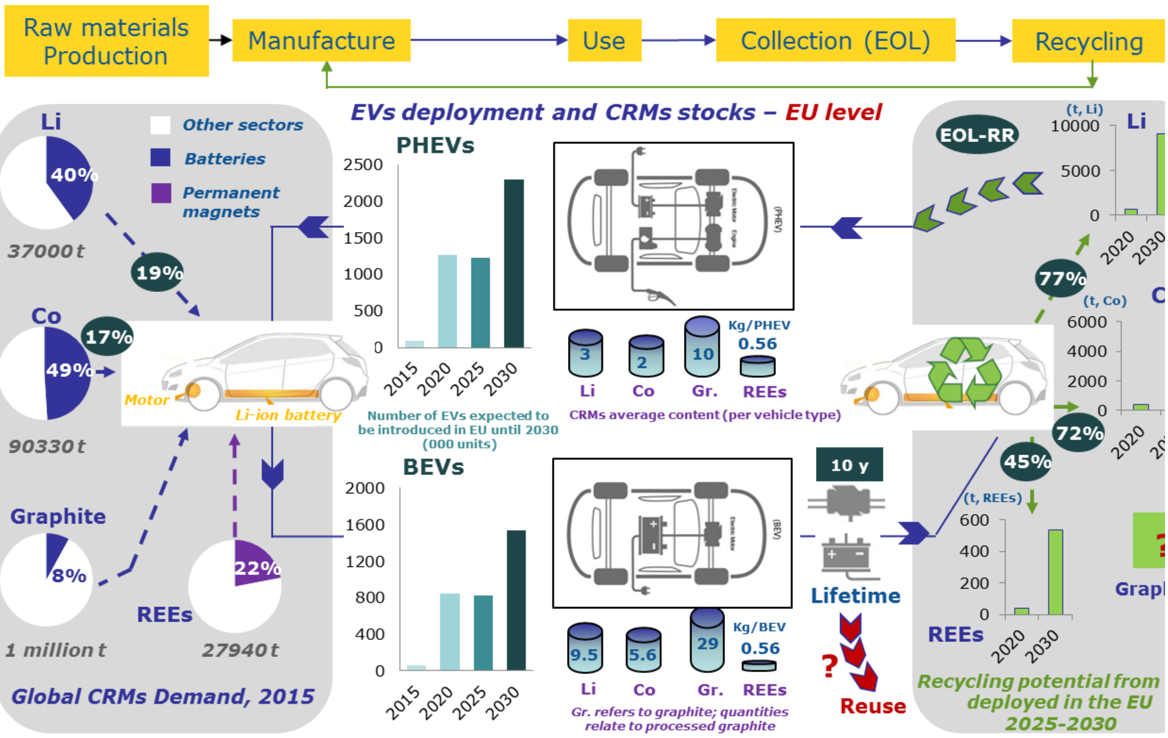

Figure 19: CRMs use in the EVs sector (battery electric vehicles (BEVs), plug-in hybrid vehicles, (PHEVs)) and potential flows resulting from recycling of EVs deployed in the EU[162]

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[158] Li-ion chemistries available include: LCO (lithium-cobalt-oxide), NMC (lithium-nickel-manganese-cobalt), NCA (lithium-nickel-cobalt aluminium-oxide), LMO (lithium-manganese-phosphate) and LFP (lithium-iron-phosphate).

[159] Available alternatives include: artificial graphite, mesocarbon microbeads, Si and Sn composites/alloys, and lithium-titanium-oxide, LTO.

[160] JRC, 2016. https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/assessment-potential-bottlenecks-along-materials-supply-chain-future-deployment-low-carbon

[161] JRC, 2016. https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/assessment-potential-bottlenecks-along-materials-supply-chain-future-deployment-low-carbon

[162] Data sources are either explained in the text or given in JRC, 2016. https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/assessment-potential-bottlenecks-along-materials-supply-chain-future-deployment-low-carbon

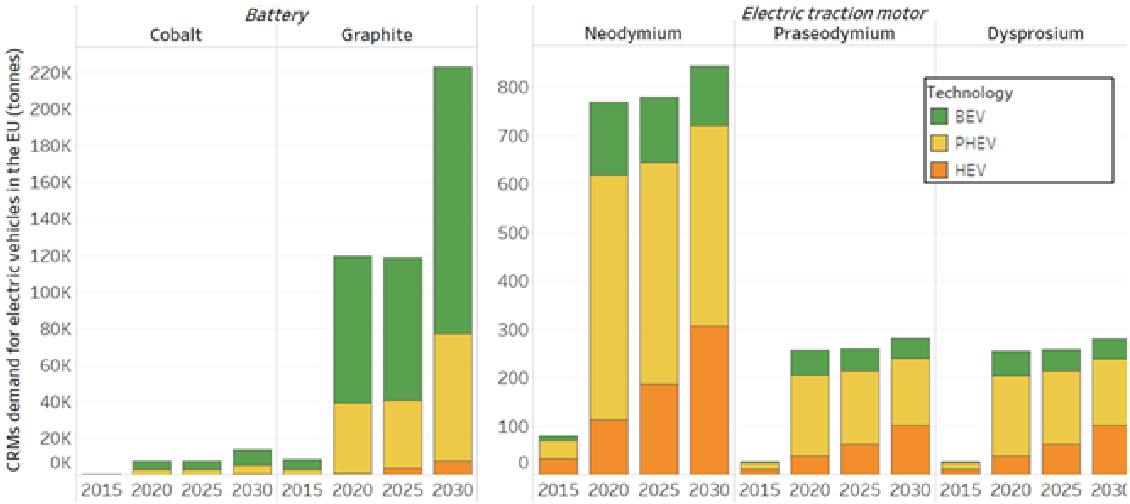

Figure 20: CRMs demand in the EU for the hybrid and electric vehicles segments[163]

Given the recent introduction of EVs on the European market, and taking into account the average lifetime of EV components (estimated to be approximately 10 years)[164], a significant number of EVs have not yet reached end-of-life. Large-scale recycling is not expected before 2020 and should only be more effective beyond 2025. Under current circumstances of low lithium and rare earth prices, high costs for technology largely untested at an industrial scale and the absence of substantial waste streams, the EU recycling infra-structure targeting EV batteries and electric motors is still weak.[165]

Currently, the material of most interest to Li-ion battery recyclers is cobalt. Specifically in the EV batteries sphere the recycling potential is significant as these batteries may be easier to collect if a dedicated system of return is established. However, specific challenges related to the declining use of cobalt in most appropriate Li-ion chemistries may make recycling unattractive, if economic practicality is not extended to the other materials such as lithium and graphite.[166] For example, whilst graphite anode materials are currently not recycled there are no obvious barriers to their recovery by hydrometallurgical and direct physical recycling processes.[167]

Regarding the rare earths contained in electric traction motors, although the current level of recycling from end-of-life permanent magnets is still very limited[168], several studies estimate the potential level of recycling of REEs to be around 40% in the next 20 years.[169]

The growth of the electric vehicle market could over time reduce demand for platinum, palladium and rhodium, though hybrid technology is still reliant on these catalysts to curb emissions. However, growth in the use of fuel cell catalysts could help to balance

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[163] Demand forecasts up to 2030 are based in penetration scenarios put forward by ERERT (European Roadmap for Electrification of Road Transport) for BEVs and PHEVs and on Avicenne Energy projections for HEVs. Details concerning the calculations are given in JRC, 2016. https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/assessment-potential-bottlenecks-along-materials-supply-chain-future-deployment-low-carbon

[164] JRC, 2016 (as above) and references therein.

[165] JRC, 2017, http://dx.doi.org/10.2760/6060

[166] CEC, 2015. Environmentally Sound Management of End-of-Life Batteries from Electric-Drive Vehicles in North America.

[167] Moradi, B. & Botte, G.G. J Appl Electrochem (2016) 46: 123. http://link.springer.com/article/10.1007/s10800-015-0914-0

[168] Recovery of rare earths from electronic waste: an opportunity for high-tech SMEs. Study for the ITRE Committee IP/A/ITRE/2014-09.

[169] JRC, 2016 (as above) and references therein.

out some of this reduction in demand.[170] Concerning the recycling of platinum, palladium and rhodium, the auto-catalysts recycling is estimated to be between 50 and 60%.[171]

It is reported that the tyre industry uses up to 75% of natural rubber consumed in the EU. An average car tyre contains 15% natural rubber by weight and a truck tyre contains an average of 30%. The management of used tyres is relatively well organised in Europe. In 2015, 92% of used tyres (vs. 51% in 1996) were either reused as second-hand tyres, reconditioned through retreading, recycled or sent to energy recovery. However, tyre recycling is an open-loop recycling, meaning that tyre-derived rubber granulates are mainly recycled in other applications than tyres as current tyre devulcanization technologies are not selective enough to get the required high quality devulcanization.[172]

Data sources

No	Name and link/ref.	Scope			Reference period / date of publ.	Language	Free / subscription	Comments
		Subsectors	CRMs	Geographic area				
1	ProSUM[173]	Vehicles	All	EU 28	2015-	English	Free	Data on stocks and flows of secondary raw materials
2	Darton Commodities. 2016. Cobalt market review, 2015-2016[174]	All sectors with specific data on Li-ion batteries	Cobalt	Global	2015-2016	English	Available upon request	
3	Roskill: Natural and Synthetic Graphite Market Outlook (2015)[175]	All sectors with specific data on Li-ion batteries	Graphite	Global	2015-2020	English	Subscription required	
4	Roskill: Rare Earths: Global Industry, Markets & Outlook[176]	All sectors with specific data on permanent magnets	REEs	Global	2015-2020	English	Subscription required	
5	Assessment of potential bottlenecks along the materials supply chain for the future deployment of low-carbon energy and transport technologies in the EU: Wind power, photovoltaic and electric vehicles technologies, time	Low-carbon energy applications (with specific chapters on EVs)	Cobalt, Graphite, REEs	EU	2015-2030	English	Free	

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[170] EC, 2015. “Report on Critical Raw Materials for the EU critical raw materials profiles”, http://ec.europa.eu/DocsRoom/documents/11911/attachments/1/translations/en/renditions/native

[171] EC, 2015. “Report on Critical Raw Materials for the EU critical raw materials profiles”, http://ec.europa.eu/DocsRoom/documents/11911/attachments/1/translations/en/renditions/native

[172] EC, 2017. "Study on the review of the list of Critical Raw Materials - Critical Raw Materials Factsheets", https://publications.europa.eu/en/publication-detail/-/publication/7345e3e8-98fc-11e7-b92d-01aa75ed71a1/language-en

[173] http://www.prosumproject.eu/

[174] http://www.dartoncommodities.co.uk/cobalt/

[175] https://roskill.com/market-report/natural-synthetic-graphite/

[176] https://roskill.com/product/rare-earths-market-outlook/

	frame: 2015-2030, JRC, 2016[177]							
6	Binnemans, Koen, et al. "Recycling of rare earths: a critical review." Journal of Cleaner Production 51 (2013): 1-22[178]	All sectors with specific data on permanent magnets	REEs	Global	2010-2020	English	Free	
7	Re-use and Second use of Rechargeable Batteries[179]	Li-ion Batteries	-	EU	2014	English	Free	
8	Battery Materials Analysis, EUROBAT[180]	Battery material analysis in the automotive batteries	Cobalt, Antimony, Graphite, REEs	EU	2009 – 2013	English	Free	
9	The Use of Potentially Critical Materials in Passenger Cars, Chalmers University of Technology[181]	Information of CRMs in automotive	Various	EU	---	English	Free	
10	Drabik and Rizos: "Circular Economy Perspectives for Future End-Of-Life EV Batteries" (forthcoming)	Li-ion batteries	Cobalt, graphite	Europe	Forthcoming	English	Free	Data on the impacts of collection and recycling rates

5.5.2 Existing EU policies

Directive 2000/53/EU on end-of life vehicles (the "ELV Directive") sets high targets required to be attained by the economic operators: 95% for reuse and recovery and 85% for reuse and recycling by an average weight per vehicle and year, as from 2015. Based on reporting so far, nearly all Member States have reached the earlier targets of 85% for reuse and recovery and 80% for reuse and recycling.

Directive 2005/64/EC on the type-approval of motor vehicles with regard to their reusability, recyclability and recoverability was adopted following the provision of Art. 7(4) of the ELV Directive to ensure that vehicle manufacturers design vehicles so that parts and materials may be reused, recycled or recovered once the vehicle comes to the end of its natural life. As a result, new vehicles may only be sold in the EU if they may be reused, recovered and recycled in line with the targets of the ELV Directive.

The Batteries Directive 2006/66/EC also applies to automotive and traction batteries.

5.5.3 Circular Economy Action Plan

There is one explicit reference to vehicles in the Circular Economy Action Plan: in the context of the EU Regulation on waste shipment[182], the Commission undertook to take further measures to help ensure that the Regulation is properly implemented stating that

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[177] https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/assessment-potential-bottlenecks-along-materials-supply-chain-future-deployment-low-carbon

[178] http://www.sciencedirect.com/science/article/pii/S0959652612006932

[179] http://www.rechargebatteries.org/wp-content/uploads/2014/04/RECHARGE-Information-Paper-on-Re-use-and-second-use-October-2014-v.14.pdf

[180] http://www.eurobat.org/sites/default/files/resource_availability-final_long_version.pdf

[181] http://publications.lib.chalmers.se/records/fulltext/162842.pdf

[182] Regulation (EC) No 1013/2006 as amended by Regulation (EU) No 660/2014

high-value waste streams, such as end-of-life vehicles, will be targeted specifically, to prevent raw materials leakage.

As a first step, in the general context of ensuring compliance with the ELV Directive, a study was commissioned to assess the implementation of the ELV Directive with emphasis on end-of-life vehicles of unknown whereabouts, in the course of which a stakeholder workshop was organised and a public consultation[183] was carried out. It emerged that there is a broad and joint understanding among stakeholders that the current procedures need further improvement to keep track of vehicles and to improve the implementation of the requirement to issue and present a certificate of destruction. This includes addressing possible loopholes, for instance through requiring evidence on the vehicle's fate during a temporary de-registration and fining owners which do not provide statement of whereabouts for temporarily deregistered vehicles. The use of economic incentives - for instance fees or refund systems - to deliver end-of-life vehicles to authorised treatment facilities has also been discussed, inter alia, in the light of experience in some Member States.

5.5.4 Best Practices

- Vehicle manufacturers have established the International Dismantling Information System (IDIS)[184] compiling information for treatment operators of end-of-life vehicles to promote the environmental and economic dismantling and treatment and to help meet the targets set in the ELV Directive.
- To facilitate the control of shipments of end-of-life vehicles and to in particular set criteria enabling to distinguish between second-hand vehicles and waste vehicles, the Member States' Waste Shipments Correspondents have agreed Guidelines for Waste Vehicles[185], in use since 1 September 2011.
- Following the Commission's recommendations to address the problem of end-of-life vehicles of unknown whereabouts, a number of Member States have amended national legislation to ensure better control of registered vehicles and avoid deregistrations that are not linked to the legal treatment of end-of-life vehicles or the legal sale as second-hand vehicles.
- Some companies have begun investing in recycling of used EV batteries in Europe (e.g. Umicore in Belgium[186], Recupyl in France[187]). Some (like *Société Nouvelle d'Affinage des Métaux*, SNAM, and Umicore) have teamed up with car manufacturers (such as Toyota[188] and PSA Peugeot Citroën[189] and Tesla[190]), to collect and recycle batteries.
- A number of research initiatives and pilot projects have been developed for assessing the reuse of batteries that are no more suitable for EVs in energy storage applications. Batteries2020[191], Energy Local Storage Advanced system (ELSA)[192], ABattReLife[193] and Netfficient[194] are examples of EU-funded projects looking at the most suitable and

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[183] http://ec.europa.eu/environment/waste/elv/index.htm

[184] http://www.idis2.com

[185] http://ec.europa.eu/environment/waste/shipments/guidance.htm

[186] http://www.umicore.com/en/industries/recycling/umicore-battery-recycling/

[187] http://www.recupyl.com/104-batteries-the-future.html

[188] http://www.gov.scot/Publications/2013/12/9124/5

[189] http://www.snam.com/upload/actu/20151208%20PR%20PSA%20SNAM_A%20-%20version%20FS.pdf

[190] https://www.tesla.com/it_IT/blog/teslas-closed-loop-battery-recycling-program

[191] http://www.batteries2020.eu/

[192] http://www.elsa-h2020.eu/

[193] http://www.abattrelife.eu/

[194] http://netfficient-project.eu/

sustainable second use applications for EVs batteries. Further calls are planned[195], requiring the consideration of the whole value chain including circular economy aspects.

5.5.5 *Possible further actions*

- Promote the adoption of labels or other tools for declaring CRM content in key vehicle components such as batteries and auto-catalysts, e.g. via standardisation.
- Request the development of European standards for material-efficient recycling of end-of-life vehicles including for CRMs.
- Provide further support to R&D and industrial-scale innovation activities for developing competitive recycling technologies focusing on materials which are currently not (or hardly) recycled, such as lithium, graphite and rare earths.
- Continue to monitor developments in the EVs market and carry out projections on related critical materials demand and stocks.
- Make national procedures on registration/deregistration more harmonised within the EU, foster exchange of information among Member States and ensure follow-up of the fate of the temporary deregistered vehicles.
- Encourage Member States to make use of economic incentives - for instance fees or refund systems - to deliver end-of-life vehicles to authorised treatment facilities.
- Make binding, if needed in a revised form, the Correspondents Guidelines No. 9 to the Waste Shipment Regulation.

See also the Technological Roadmap to Near Zero Waste in ELV[196] of the Horizon 2020 project NEW_InnoNet.

5.6 Renewable energy

5.6.1 *Data and data sources*

The markets for wind and photovoltaic (PV) energy technologies have been growing rapidly in recent years, and are expected to account for a large share of renewable energy growth in the coming years.

Wind and PV energy technologies rely on a variety of materials including six CRMs, namely neodymium (Nd), praseodymium (Pr), dysprosium (Dy), indium (In), gallium (Ga), and silicon metal (Si) (see Figure 21). The EU demand for these materials will evolve in future depending on the deployment rates of wind and PV energy technologies and the technology mix. For instance, most of the wind turbines currently installed in the EU do not use permanent magnet generators and thus do not require rare earths. However, the situation can significantly change in the next 10-15 years due to sizing up of the wind energy: introduction of large and more efficient turbines as well as more offshore wind power may entail a higher use of permanent magnets. The projected evolution in the EU demand for the six CRMs is given in Figure 22[197]. Big economies such as China and USA have ambitious plans for clean energy deployment, even if they may not depend to the same extent as Europe on offshore based deployment of wind power using permanent magnets. EU manufacturers could thus face more competition for the same material supplies.

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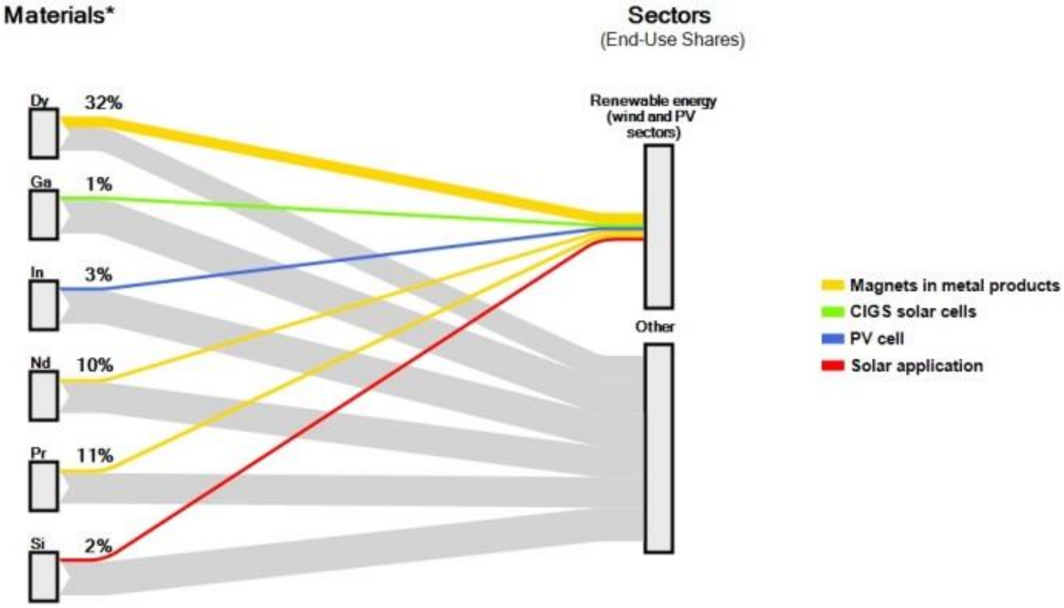
[195] https://ec.europa.eu/inea/en/horizon-2020/green-vehicles

[196] http://www.newinnonet.eu/ReportsList.aspx

[197] Silicon demand in Figure 22 denotes the amount of solar grade silicon required to achieve the PV deployment rates.

Several projects dedicated to permanent magnet recycling are either approved or under way in China[198]. Currently, there is no recycling of these rare earths in the EU. Up to 2030, most of the wind turbines will still be in operation (assuming a 30 years lifetime).

Recycling of Si, In, Ga from PV modules, alongside other raw materials such as glass, aluminium, copper and silver, has a high potential: more than 95% is claimed as an economically feasible recycling rate.[199] PV modules have a considerable lifetime - more than 25 years – meaning that this still young technology has generated little waste so far. Yet, the potential is huge: between 2 and 8 million tonnes of PV waste is estimated to be generated globally in 2030, increasing to 60-75 million tonnes by 2050.[200]



* Only a subset of all CRMs used in renewable energy sector is included.

Figure 21: Share of CRMs used in the renewable energy sector (wind and PV) (JRC Elaboration based on 2017 CRM assessment)

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[198] Roskill, 2015. Rare Earths: Market Outlook to 2020, 15th edition 2015, London UK, ISBN 978 0 86214 618 4.

[199] BINE, 2010. Bine Informationdienst, Recycling photovoltaic modules, Projektinfo 02/10. http://www.bine.info/fileadmin/content/Publikationen/Englische_Infos/projekt_0210_engl_internetx.pdf

[200] End-of-Life Management, Solar Photovoltaic Panels, IRENA 2016 and IEA-PVPS; http://www.irena.org/DocumentDownloads/Publications/IRENA_IEAPVPS_End-of-Life_Solar_PV_Panels_2016.pdf

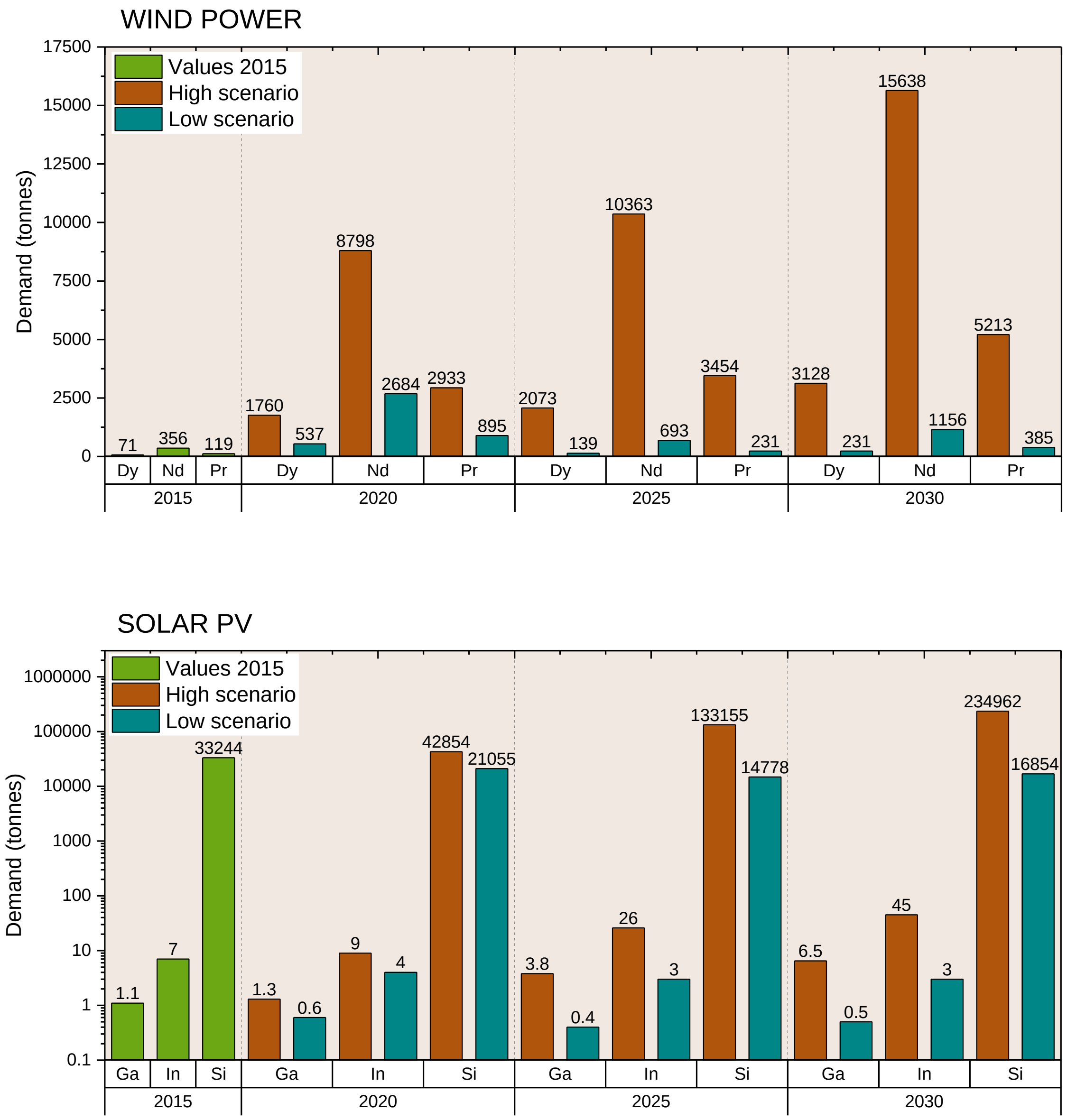

Figure 22: Projected evolution in EU demand for the six CRMs required in wind and PV sectors: existing low and high deployment scenarios considered. (Note that for the SOLAR PV diagram the scale is logarithmic.)

Data sources

No	Name and link/ref	Scope			Reference period / date of publ.	Language	Free / subscription	Comments
		Subsectors	CRMs	Geographic area				
1	Assessment of potential bottlenecks along the materials supply chain for the future deployment of low-carbon energy and transport technologies in the EU: Wind power, photovoltaic and electric vehicles technologies, time frame: 2015-2030,	Wind and PV	Nd, Dy, Pr, Si, In, Ga	Europe	2016	English	Free	

	JRC[201]							
2	Energy Transition and Demand for Raw Materials, The Hague Centre for Strategic Studies[202]	All	Various	Global	2017	English	Free	
3	Wind energy scenarios for 2030, A report by EWEA, the European Wind Energy Association [203]	Wind	Nd, Dy, Pr	Europe	2016	English	Free	
4	Solar Power Europe (SPE). European Photovoltaic Industry Association. Global Market Outlook For Solar Power / 2016 – 2020[204]	PV	Si, In, Ga	Europe	2016	English	Free	
5	EU reference scenario 2016. Energy, transport and GHG emissions. Trends to 2050, European Commission[205]	Wind and PV	Nd, Dy, Pr, Si, In, Ga	Europe	2016	English	Free	
6	Recycling of photovoltaic modules, BINE 2010[206]	PV	Si, In, Ga	Europe	2010	English and German	Free	
7	IRENA, International Renewable Energy Agency and Energy Technology System Analysis Programme. Solar Photovoltaic. Technology Brief; 2013[207]	PV	Si, In, Ga	Europe	2013	English	Free	
8	Roskill, 2015. Rare Earths: Market Outlook to 2020, 15th edition 2015	Wind	Nd, Dy, Pr,	Global	2015	English	Subscription	
9	Photovoltaic module decommissioning and recycling in Europe and Japan[208]	PV	Si, In, Ga,	Europe and Japan	2015	English	Free	
10	PV CYCLE[209]	PV	Si, In, Ga				Free	

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[201] https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/assessment-potential-bottlenecks-along-materials-supply-chain-future-deployment-low-carbon

[202] http://www.rawmaterialsconference.nl/uploaded/docs/Raw_materials/Policy_Paper_Raw_Materials_04_09_2017.pdf

[203] http://www.ewea.org

[204] http://www.solarpowereurope.org

[205] https://ec.europa.eu/energy/sites/ener/files/documents/20160713%20draft_publication_REF2016_v13.pdf

[206] http://www.bine.info/fileadmin/content/Publikationen/Englische_Infos/projekt_0210_engl_internetx.pdf, http://www.bine.info/publikationen/publikation/recycling-von-photovoltaik-modulen/

[207] http://www.irena.org

[208] http://stud.epsilon.slu.se/7608/1/auer_a_150211.pdf

[209] http://www.pvcycle.org

5.6.2 *Existing EU policies*

Renewable Energy is at the core of the Energy Union's priorities. The Renewable Energy Directive (2009/28/EC), setting European and national binding renewables targets for 2020, has been and will continue to be a central element of the Energy Union policy, in view of making the EU world number one in renewables. T**he EU as a whole is well on track to reach the 20% target by 2020.** However, some Member States will have to step up their efforts in order to reach their national targets.

The Commission's proposal for a revised Renewable Energy Directive[210] aims at further strengthening the European dimension of renewable energy policy, to make the EU a global leader in renewable energy and to ensure that the target of at least 27% renewables in the final energy consumption in the EU by 2030 is met.

The Ecodesign Working Plan 2016-2019 includes solar panels and inverters as a group of products that hold a significant potential for saving energy. A dedicated study will be launched for investigating this potential, but also looking at aspects supporting material efficiency issues such as durability and recyclability. These aspects should enable an efficient use of CRMs in solar panels and inverters.

5.6.3 *Best Practices*

- Sweden: Early adoption of mandatory recycling targets (under the WEEE Directive) for PV systems to encourage higher recycling and recovery rates.[211]
- The PV CYCLE association[212], established in 2007, collects PV waste for treatment free of charge, already recycling solar panels (mainly production scrap, panels damaged during delivery or installation or failed before reaching end-of-life) from Spain, Germany, Italy, Belgium, Greece and the Czech Republic.
- EU support to the development and demonstration of material efficient solutions for equipment used in wind (e.g. the Horizon 2020 project NEOHIRE[213] on the use of REE, Co and Ga in permanent magnets) and PV (e.g. the LIFE project FRELP[214]) energy technologies.

5.6.4 *Possible further actions*

- Examine whether the EU should develop a specific policy for eco-design of wind turbines (under the Ecodesign Directive) and/or their end-of-life management, in support of the manufacturing and recycling sectors concerned.

- Provide dedicated support to innovation and research actions fostering material efficient solutions in the use of CRMs in wind and PV energy technologies.

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[210] COM(2016) 767

[211] Photovoltaic module decommissioning and recycling in Europe and Japan– current methodologies, norms and future trends, Master's Thesis • 30 HEC, Swedish University of Agricultural Sciences; http://stud.epsilon.slu.se/7608/1/auer_a_150211.pdf

[212] http://www.pvcycle.org

[213] http://neohire.eu

[214] https://frelp.info

5.7 Defence industry

5.7.1 Data and data sources

The defence industry in Europe depends on a variety of raw materials, which are necessary to build a large spectrum of key defence capabilities. Thirty-nine raw materials have been identified as “important”[215] for production of high-performance processed and semi-finished materials (e.g. alloys, composites, etc.) needed for manufacture of a large variety of defence-related components and subsystems.[216]

Seventeen of these thirty-nine raw materials are evaluated in 2017 as CRMs[217] (Table 3).

Table 3: Critical raw materials (2017 list) used in the European defence industry, their role in defence industry and major end-use defence sectors (JRC source[216])

Critical raw material	Role in defence industry	Major end-use defence sub-sector
Beryllium	As an oxide and in various alloys with copper or aluminium to produce different components, for instance in fighter airframes, landing gears, connectors, electronic/optical systems for communication and targeting	Aeronautics, naval, electronics
Cobalt	Mainly in nickel-based superalloys for turbine, compressors and fans in fighter aircraft propulsion, and in electric motors (magnets) and batteries in combination with samarium and other elements (e.g. nickel or lithium)	Aeronautics, naval
Dysprosium	As a minor additive in high-powered neodymium-iron-boron (NdFeB) permanent magnets for electric motors, guidance, control systems, actuators and amplifications (e.g. voice coil motors and audio speakers, satellite communication)	Missiles
Gallium	Communication (e.g. transmitter) and electro-optical systems and on-board electronics as gallium arsenide and gallium nitrite; missile guidance	Electronics
Germanium	On-board electronics for inertial and combat navigation, IR tracking systems, binoculars (including night vision), GPS/SAL guidance system; canopy; as substrate in solar cells powering military satellites	Electronics
Hafnium	As oxide in electro-optical systems for radar and in a small percentage of superalloys for aircraft propulsion	Aeronautics, electronics
Indium	Laser targeting, sensors, identification equipment for IR imaging systems and inertial navigation as well as in on-board electronics for phased array radar	Electronics
Neodymium	Component of high-powered neodymium-iron-boron permanent magnets for a variety of applications: electric motors, guidance, control systems, actuators and amplifications (e.g. voice coil motors and audio speakers,	Aeronautics, space, electronics

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[215] The term ‘important’ is used to denote materials with unique properties, necessary to fulfil the stringent requirements of defence applications.

[216] C.C. Pavel, E. Tzimas. JRC report: Raw materials in the European defence industry. EUR 27542 EN; doi:10.2790/0444.

[217] https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

	satellite communication, etc.); in lasers as neodymium: yttrium-aluminium-garnet crystals	
Niobium	Guidance section of missiles and in small quantities in composition of nickel super- alloys for high-temperature section of jet turbines	Aeronautics, missiles
Platinum	Thin coating of turbine blades (to increase thermal barrier) in combination with nickel and aluminium	Aeronautics
Praseodymium	In neodymium-iron-boron permanent magnets (usually in mixture with neodymium in a ratio Nd:Pr=4:1) with the same applications as for neodymium	Missiles
REEs (other[218])	Rather limited and specialised application in defence, such as magnets, radar (signal generation, surveillance and missile launch detection), lasers, sensors, other electronic components, phosphor (avionic display), heat-resistant superalloys and steel alloys	Aeronautics, electronics
Samarium	With cobalt in samarium-cobalt permanent magnets used in electric motors and diesel electric for propulsion, and electronic applications	Aeronautics, naval, electronics
Tantalum	Capacitors for on-board applications: binoculars, identification equipment/IR, inertial navigation, radars; in superalloys used in jet turbines and other propulsion systems; as a liner in shaped charges and explosively shaped penetrators	Aeronautics, electronics
Tungsten	Alloy element for ballast, warheads, shaped charges, throats, soldering, electrics, armour piercing and tank ammunition; also used in alloys in aeronautics for shells (arrowhead), fuselages, wings and turbine engines; tungsten carbide is essential for cutting machines	Aeronautics, land
Vanadium	Additive to improve the resistance to wear and deformation of steel; vanadium-containing alloys are used for the hull of submarines, in structural parts, engines and landing gear, but also in gun alloy elements, armour, fuselages and wings	Aeronautics, naval
Yttrium	Laser crystals for targeting weapons, finding and sight communication, electrolyte for fuel cells, phosphors for display screens, vision and lighting; in composition in equipment for signal generation, detection and surveillance, in thermal barrier coatings, and as alloying element for special steel grades	Electronics

The aeronautic and electronic defence sub-sectors are the major users of CRM (and the most vulnerable to potential material supply constraints).

Precise information on the type, composition and quantity of materials used in the European defence applications is limited mainly due to sensitivity reasons. Accurate information about the reuse of waste streams generated during production of high-tech components for defence applications, management of the end-of-life military products and recycling of materials from these products is not readily available either.

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[218] Other REEs: cerium, erbium, europium, gadolinium, holmium, lanthanum, lutetium, scandium, terbium, thulium, ytterbium.

Overall, technological and economic barriers to recycle critical and scarce materials from defence industry could be expected. From an economic perspective, raw materials represent for some applications only a small fraction of the total value of the product (for example, the value of the materials contained in a jet engine may account for no more than up to 2 % of the engine cost[219]). Even though an alloy which is recycled from defence or civil applications contains valuable and high priced CRMs, the separation into its constituents might not be cost-effective.

In the aerospace industry recycling of materials from aircraft was not under a major consideration until recently and little information is currently available, in particular in official statistics. Now it has become a common practice to account for all metals used in the aerospace industry, for instance in the manufacture of a jet engine; any excess metal is fed into a closed-loop recycling operation.[220] Some publications argue that now the recycling rate of an aircraft has reached about 60 % and the aerospace industry is aiming to increase it to 80-90%.[221] Carbon fibre composite materials are becoming more popular in the aeronautic applications, such as jet fighters, and large industrial players (e.g., Airbus, Boeing, etc.) have already initiated programmes for recycling the carbon-fibre material. Aluminium, magnesium, titanium as well as steel are several materials which are currently recycled both from waste generated during the production of aircraft structure and engine components and from reclaimed components from retired aircraft. However, other CRMs such as rare earth elements are still recycled only in small quantities, mainly from permanent magnet scrap.

Data sources

No	Name and link/ref.	Scope			Reference period / date of publ.	Language	Free / subscription	Comments
		Subsectors	CRMs	Geographic area				
1	JRC report, Raw materials in the European defence industry; EUR 27542 EN; doi:10.2790/0444[222]	Air, Naval, Land, Space, Electronic Missile		EU	2016	English	Free	
2	US National Academy of Science, Managing Materials for a Twenty-first Century Military[223]	Military sector	Rare earth elements, beryllium	USA	2008	English	Free	
3	US Department of Defence, Strategic and critical materials 2015 Report on stockpile requirements[224]	Military sector	Various	USA	2015	English	Free	
4	Marscheider-Weidemann, F., Langkau, S., Hummen, T., Erdmann, L., Tercero Espinoza, L., Angerer, G., Marwede, M. & Be-	Emerging technologies	Several	Germany	2016	German	Free	'Raw materials for emerging technologies 2016'

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[219] Strategic materials: technologies to reduce U.S. import vulnerabilities. Washington, DC: U.S. Congress, Office of Technology Assessment, OTA-ITE-248, May 1985: https://www.princeton.edu/~ota/disk2/1985/8525/8525.PDF.

[220] US National Academy of Science, Managing Materials for a Twenty-first Century Military. Washington, D.C. 2008, p. 89.

[221] A.P. Mouritz, Introduction to aerospace materials. Elsevier. May 2012, p. 560.

[222] https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/raw-materials-european-defence-industry

[223] https://www.nap.edu/catalog/12028/managing-materials-for-a-twenty-first-century-military

[224] https://www.hsdl.org/?view&did=764766

	necke, S. (2016): Rohstoffe für Zukunftstechnologien 2016. DERA Rohstoffinformationen 28; 353 S., Berlin. March 2016[225]							
5	MSA study[226]	Defence sector	CRMs (2014)	EU	2015	English	Free	

5.7.2 Existing EU policies

On 30 November 2016 the Commission adopted the European Defence Action Plan[227]. It sets out concrete proposals to support a strong and innovative European defence industry and defence capability priorities agreed by EU countries. It will do this by mobilising available EU instruments to ensure that the European defence industrial base is able to meet Europe's future security needs.

The main measures proposed are:

- a European Defence Fund to fund collaborative research projects as well as the joint development of defence capabilities, to be owned by EU countries, in priority areas;
- supporting SMEs through fostering investments in defence supply chains;
- ensuring Europe has an open and competitive single market for defence.

Security of supply is considered to be a cornerstone in the establishment of a genuine single market for defence. This is why the Commission will identify bottlenecks and supply risks linked to the materials that are needed for the development of key capabilities. This work, planned to take place in 2018, will build on the findings of a first study, undertaken by the JRC[228]. The outcome of the work may provide valuable inputs to future EU research programmes which could contribute to mitigating supply risks, for example through substitution of CRMs.

5.7.3 Best Practices

(No relevant best practice identified at this stage.)

5.7.4 Possible further actions

- Collect information about material supply chains for semi-finished defence products and determine whether the defence-based European industries are exposed to supply risks based on specific assessments.
- Provide support to collaborative defence research funding to mitigate supply risks linked to raw materials needed for the development of key defence capabilities by Europe's defence industry and to find solutions for improving resource efficiency, recycling and substitution of relevant raw materials.

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[225] https://www.bgr.bund.de/DERA/DE/Downloads/Studie_Zukunftstechnologien-2016.pdf;jsessionid=A996A13E9E2764B203496C746AB0D6D4.1_cid284?__blob=publicationFile&v=5

[226] https://ec.europa.eu/jrc/en/scientific-tool/msa

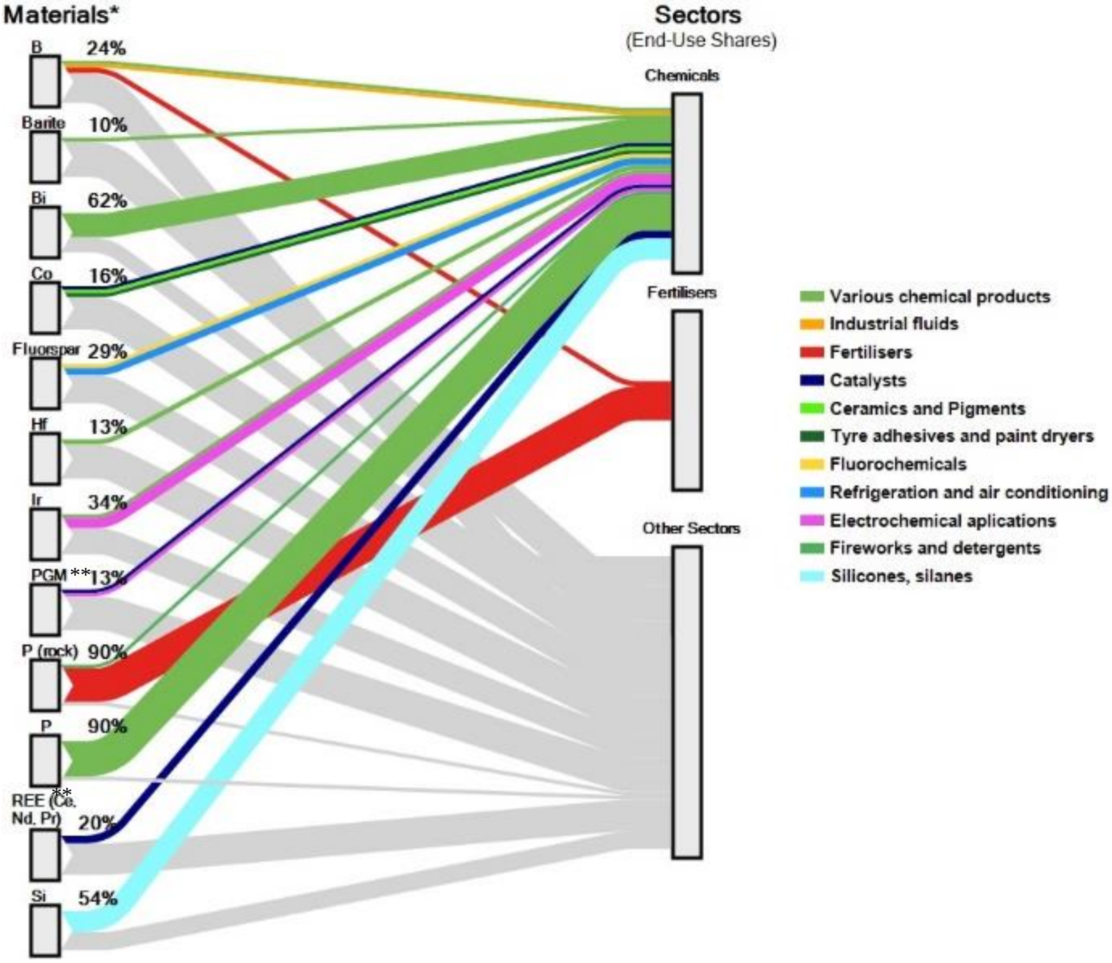
[227] COM(2016)950

[228] Pavel, C. and Tzimas, E., Raw materials in the European defence industry. Luxembourg, European Commission, joint Research Centre (JRC), 2016.

5.8 Chemicals and fertilisers

5.8.1 Data and data sources

The production of several chemicals and fertilisers in Europe relies on many CRMs (see Figure 23), such as: antimony, baryte; bismuth; borate; cobalt; fluorspar; hafnium; natural graphite; niobium; platinum-group metals (PGMs); phosphate rock; phosphorus; rare earth elements (REE); silicon metal; tantalum; tungsten; vanadium.



*Only a subset of CRMs used in chemicals and fertilisers are included. **Average share for: Pt, Pd, Rh, Ru in PGM (except Ir); Ce, Nd, Pr in REE. 'P (rock)' means phosphate rock.

Figure 23: Share of CRMs used in chemicals and fertilisers according to the 2017 CRM assessment[229]

The main applications of CRMs in the chemical and fertilisers sectors include their use in the production of catalysts, fertilisers, polymers, pharmaceutics and dyes. Examples include: 86% of phosphate rock is used in the production of fertilisers; 90% of white phosphorus is used in the production of detergents and other chemicals; 60% of bismuth is used in the manufacture of pharmaceuticals and other chemicals; and 54% of silicon metal is used for making silicones and silicates (final applications in e.g. shampoos, fixing materials and insulating materials).

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[229] JRC elaboration based on data from the 2017 EU criticality assessment. The chemical and fertilisers sectors consists mainly in the NACE sectors C20 - Manufacture of chemicals and chemical products.

Chemicals containing CRMs are produced for a broad variety of other sectors, e.g. 43% of antimony is used in the production of flame retardant chemicals, which are incorporated in polymers used mainly in the electric and electronic equipment sector (see Section 5.3). Therefore, the overall importance of CRMs for the manufacturing industry is higher than what is presented in Figure 23.

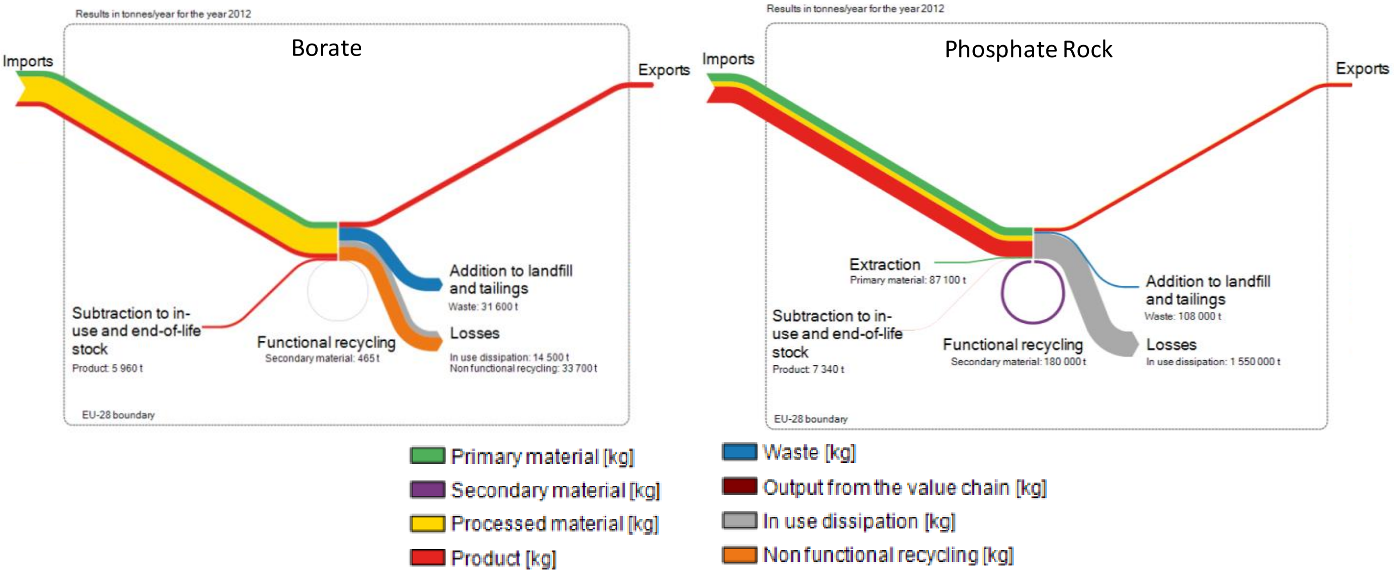

Figure 24: Examples of flows of CRMs used in chemicals and fertilisers based on 2015 MSA study

According to the MSA study[230], CRMs used in several chemical applications are lost to the environment due to dissipative use or to landfill. Examples of these losses include: natural graphite used in lubricants, silicones used in different chemicals, tungsten used in the production of catalysts and a large percentage of borates and phosphates used in fertilisers.

For borates and phosphates, the sources of secondary materials are biogenic wastes (e.g. manure or other animal by-products, bio- and food wastes, wastewater)[231], for which recycling is considered as functional (see Figure 24) because it replaces primary boron and phosphorus. The recycling of phosphorus rich wastes can also help prevent water eutrophication.

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[230] https://ec.europa.eu/jrc/en/scientific-tool/msa

[231] Schoumans, OF, Bouraoui, F, Kabbe, C, Oenema, O, van Dijk, KC. Phosphorus Management in Europe in a Changing World, 44, 180–92, 2015.

Data Sources:

No	Name and link/ref.	Scope			Reference period / date of publ.	Language	Free/ subscription	Comments
		Subsectors	CRMs	Geographic area				
1	Eurostat: data on P gross balance[232]	Fertilisers	Phosphorus	EU 28	2006-2015	English	Free	Data on P gross balance, including consumption of fertilisers, P inputs and removals from soil
2	Eurostat: data on chemical production[233]	Chemicals	-	EU 28	1995-2015	English	Free	Chemical production statistics (PRODCOM), NACE 2 sector 20
3	LUCAS: Land Use/ Land Cover Area Frame Survey[234]	Land Use/ Land Cover	Phosphorus	LUCAS Soil Survey 2009/2012 : EU 27 2015: EU 28	2009/ 2012 and 2015 Next soil survey in 2018	English	Free	Information on physical and chemical properties of topsoil (0-20 cm) in the EU, including concentration of Phosphorus
4	FAO Statistics on fertilisers[235]	Various (including Fertilisers)	Phosphorus	World	2002-2014	English	Free	Information on fertilisers flows.
5	Van Dijk et al., 2016 [236]	Various (including Fertilisers)	Phosphorus	EU 27	2005	English	Free	Phosphorus flows in EU-27 and its Member States, including food and non-food production, consumption, and waste.

5.8.2 *Existing EU policies*

The existing Fertilisers Regulation (No 2003/2003) ensures free movement on the internal market for fertiliser products belonging to one of the product types included in Annex I to the Regulation. Such products may be labelled 'EC-fertilisers'. Companies wishing to market products of other types as EC-fertilisers must first obtain a new type-approval through a Commission decision amending that Annex. Around 50% of the fertilisers currently on the EU market, including virtually all fertilisers produced from organic materials, such as animal or other agricultural by-products or recycled bio-waste from the food chain, are currently not included in the Annex.

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[232] http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=aei_pr_gnb&lang=en

[233] http://ec.europa.eu/eurostat/web/prodcom/overview

[234] http://ec.europa.eu/eurostat/web/lucas/overview

[235] http://www.fao.org/faostat/en/#data

[236] van Dijk, KC, Lesschen, JP, Oenema, O. Phosphorus Flows and Balances of the European Union Member States, Science of The Total Environment, 542, 1078–93, 2016.

5.8.3 Circular Economy Action Plan

The Commission undertook in the Circular Economy Action Plan to propose a revised EU Regulation on fertilisers, so as to facilitate recognition of organic and waste-based fertilisers in the single market and thus encourage the recycling of bio-nutrients as fertilising products in the circular economy.

On 17 March 2016, the Commission proposed a Regulation[237] to harmonise EU rules for products derived from organic waste and by-products and to provide rules for the safe recovery of nutrients into secondary raw materials; when organic waste fulfils strict rules, it can become a component of CE-marked fertilising products with unrestricted access to the single market.

5.8.4 Best Practices

- The recycling of CRMs from spent catalysts used in the chemicals sector: In 2012, the European Catalysts Manufacturers Association produced general guidelines for the management of spent catalysts that can be applied for recycling CRMs.[238] PGMs recycling from catalysts used in chemical processes achieves recycling rates of 80-90%.[239]

5.8.5 Possible further actions

- Support the development of new or optimisation of existing chemical processes and/or technologies that enable/enhance the safe recycling and/or reuse of CRMs.

6 CONCLUSIONS AND OUTLOOK

As set out in the Circular Economy Action Plan of 2015, this Report provides key data sources, suggests a number of best practices and identifies options for further action, in order to ensure a coherent and effective EU approach to CRMs in the context of the transition to a circular economy. The possible further actions presented in the report (see Annex III for an overview) are to be further assessed before deciding whether or not they should be implemented by the Commission.

The Commission welcomes the views of Members States and stakeholders on this report, and will use the Raw Materials Supply Group (a Commission expert group) and the European Innovation Partnership on Raw Materials, as well as other relevant (specific) forums to consult on further measures to be taken so as to properly address issues in relation to CRMs in the transition to a circular economy.

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[237] https://ec.europa.eu/transparency/regdoc/rep/1/2016/EN/1-2016-157-EN-F1-1.PDF

[238] ECMA, Ecma Guidelines For The Management Of Spent Catalysts, 2012.

[239] Hagelüken, C, Recycling the Platinum Group Metals: A European Perspective, Johnson Matthey Technology Review, 56, 29-35, 2012.

Annex I. Major applications of CRMs and information on recycling (JRC elaboration based on the 2017 CRM study and on the MSA study 2015)

CRM	Major applications	Recycling	
		End-of-life recycling input rate	Recycling from products at end-of-life
Antimony	Flame retardants; Lead acid batteries; Lead alloys	28%	Secondary antimony is mainly recovered from lead-acid batteries
Baryte	Weighting agent in oil and gas well drilling fluids or “muds”; Filler in rubbers, plastics, paints & paper; Chemical industry	1%	Little baryte is recovered at drilling sites
Beryllium	Electronic and telecommunications equipment; Transport and Defence (Vehicle electronics, Auto components, Aerospace components)	0%	Beryllium is not recycled from end-of-life products
Bismuth	Chemicals; Fusible alloys (low-melting alloys) & other alloys; Metallurgical additives	1%	Bismuth is difficult to recycle because it is mainly used in many dissipative applications, such as pigments and pharmaceuticals.
Borates	Glass (insulation); Glass (excl. insulation); Frits and Ceramics; Fertilisers	0.6%	Borates can be replaced by secondary sources from the recycling of biogenic waste flows such as food and vegetal waste, manure and sewage sludge
Coking coal	Base metal production	0%	The end-of-life recycling input rate for coking coal is estimated to be zero
Cobalt	Battery chemicals, Superalloys, hardfacing/HSS and other alloys; Hard materials (carbides and diamond tools)	35%	Cobalt-bearing end-of-life scrap can be in the form of used turbine blades or other used parts from jet engines, used cemented carbide cutting tools, spent rechargeable batteries, magnets that have been removed from industrial or consumer equipment, spent catalysts, etc.
Fluorspar	Solid fluoropolymers for cookware coating and cable insulation; Refrigeration and air conditioning; Steel and iron making; Fluorochemicals; Aluminium making and other metallurgy	1%	Although fluorspar itself is not recyclable, a few thousand tons of synthetic fluorspar are recovered each year during uranium enrichment

CRM	Major applications	Recycling	
		End-of-life recycling input rate	Recycling from products at end-of-life
Gallium	Integrated circuits; Lighting	0%	The rate of recovery of gallium from end-of-life products is close to zero and this is due to the difficulty and cost to recover it from highly dispersed items
Germanium	Optical fibres; Infrared optics; Satellite solar cells	2%	Only a small amount of germanium is recycled from old scrap of IR optics such as used mobile phones
Hafnium	Base metals; Machinery parts; Chemical products; Optics	1%	It is likely that little to no post-use recycling is being carried out currently, given its contamination in the nuclear industry and the low percentage content in super alloys
Helium	Cryogenics; Controlled atmospheres; Welding; Pressurisation and purging; Semiconductors, optic fibres; Balloons	1%	Helium used in large-volume applications is seldom recycled
Indium	Flat panel displays; Solders	0%	Very little old scrap is recycled worldwide because of minor indium concentrations in final products, a lack of appropriate technology, or low economic incentives compared to recycling costs
Magnesium	Transportation; Packaging; Desulphurisation agent	13%	In the EU, a large share of magnesium is used as an alloying element in the production of aluminium alloys and derived applications. Most of end-of-life magnesium scrap is recycled as part of the aluminium value stream. Magnesium alloys are entirely recyclable once they are collected from end-of-life products
Natural Graphite	Refractories for steelmaking; Refractories for foundries	3%	Efforts toward recycling post-consumer products containing natural graphite are dampened by oversupply and low prices. There is some recycling of used refractory material
Natural rubber	Automotive	1%	End-of-life recycling is limited either due to contamination issues or due to the impossibility to recycle the application
Niobium	Steel (structural, automotive, pipeline)	0%	The amount of niobium physically recovered from scrap is negligible

CRM	Major applications	Recycling	
		End-of-life recycling input rate	**Recycling from products at end-of-life**
PGMs	Autocatalyst; Jewellery; Electronics	11% *	The high value of PGMs makes their recycling attractive. The majority of the recycling volumes come from the recycling of spent automotive catalysts and electronics
Phosphate rock	Mineral fertilizer; Food additives	17%	Phosphate rock can be replaced by secondary sources of phosphorus from the recycling of biogenic waste flows such as food and vegetal waste, manure and sewage sludge
Phosphorus	Chemical industry applications	0%	
REEs (Heavy)	Phosphors: lighting, displays; Magnets; Chemical (other)	6% *	Recycling of REEs is often difficult because of the way they are incorporated as small components in complex items or as part of complex materials. The processes required for recycling are energy intensive and complex
REEs (Light)	Magnets; Glass Polishing; FCCs; Metallurgy	7% *	
Scandium	Solid Oxide Fuel Cells; Al-Sc alloys	0%	No recycling circuit is known for scandium in end-of-life products
Silicon metal	Chemical applications; Aluminium alloys	0%	Silicon metal is not currently recovered from post-consumer waste. Most chemical applications are dispersive, thus not allowing for any recovery. There is research on recycling of silicon wafers, however it has not yet materialised in marketable solutions
Tantalum	Capacitors; Aerospace; Sputtering targets; Mill products; Carbides	1%	Tantalum can be recovered from end-of-life capacitors and spent sputtering targets
Tungsten	Mill and cutting tools; Mining and construction tools; Other wear tools	42%	Recycling of tungsten in high speed steel is high. On the other hand, recycling in applications such as lamp filaments, welding electrodes and chemical uses is low because the concentration is low and therefore not economically viable
Vanadium	Ferrovanadium; Tubes and pipes; Turbines and electromotors	44%	Two kinds of secondary vanadium scrap can be discerned: steel scrap, recycled along with the vanadium content, and spent chemical process catalysts

* average values

Annex II. Examples of CRMs discussed in Ecodesign preparatory studies

Year of conclusion	**Preparatory study on:**	**Details**
2007	Space and combination heaters	The study mentions the use of PGMs in catalytic combustion
2007 (review on-going)	Personal computers and servers	The initial study discussed the content of silicon in computers. The on-going revision study specifically mentions the EU CRMs and it analyses their content in the products (based on research conducted by JRC)
2010	Sound and Imaging Equipment	The study discusses the content of silicon in the products
2007 (review on-going)	Televisions / electronic displays	The initial study discusses the content of indium (as ITO) in the products. Potential measures on the declaration of indium were discussed in the review process (based on a research conducted by JRC)
2007	Linear and compact fluorescent lamps	The study discusses the presence of some materials such as REEs, gallium and indium
2007 (review on-going)	Domestic washing machines	The review study discusses the content of REEs in motors
2007 (review 2017)	Domestic dishwashers	The review study specifically mentions the EU CRMs and it discusses the content of REEs in motors
2007	Simple set top boxes	The study discusses content of silicon metal in products
2007	Domestic lighting; incandescent, halogen, LED and compact fluorescent lamps	The study discusses the content of some CRMs (such as gallium and indium) in the products.
2008	Electric motors	The study mentions some REEs used in high performance motors
2009	Room air conditioning appliances, local air coolers and comfort fans	The study discusses the content of REEs and their relevance for high efficiency motors
2009	Directional lighting: luminaires, reflector lamps and LEDs	The study discusses the content of some CRMs (such as gallium and indium) in the products
2011 (review 2015)	Ventilation fans in non-residential buildings	The review study discusses the content of REEs and the relevance of their recycling
2014	Uninterruptible Power Supplies	The study mentions the use of some CRMs (such as gallium, cobalt, silicon) to improve efficiency
2014	Electric Motors and Drives	The study discusses the use of some REEs in high-performance magnets
2015	Power cables	No CRM was found relevant for this product group
2015	Enterprise servers	The study specifically refers to CRMs and is a first example of a study which assesses the content of CRMs in the products (based on research conducted by JRC)
2015	Light Sources	The study specifically refers to the CRMs and is a first example of a study which specifically assesses the content of CRMs in the products

Annex III. Overview of possible further actions by sector and EU policy area

Sector / policy area	EU industrial and raw materials policy	EU environment policy	EU research and innovation policy	Other EU policies
General		Workshop for Member States on CRMs under the Waste Framework Directive.		
Mining	Improve pan-European data acquisition, collection and management on the composition of mining waste; Develop tools to assess feasibility of recovery of CRMs from mining wastes.		Development of technologies to efficiently extract CRMs from primary ores and extractive wastes.	
Landfills	Promote the recovery of CRMs from landfills.			
Electrical and electronic equipment	Under the Ecodesign Directive, consider requirements on easier extraction at end-of-life of key components containing CRMs or declaring the content of CRMs.	Explore the potential of new satellite technologies to detect e-waste crime.		
Batteries	Promote suitable design for disassembly of EEE so that batteries can be readily removed.			
Automotive sector	Promote labels or other tools for declaring CRM content in key vehicle components; Request the development of European standards for material-efficient recycling of end-of-life vehicles including for CRMs; Monitor developments in the EVs market and carry out projections on related CRM demand and stocks.	Encourage Member States to use economic incentives to deliver end-of-life vehicles to authorised facilities; Make the Waste Shipment Correspondents Guidelines No. 9 binding.	Development of recycling technologies focusing on materials which are currently not recycled.	Make vehicle registration/ deregistration more harmonised and foster exchange of information among Member States.
Renewable energy	Include eco-design of wind turbines under the Ecodesign Directive.		Research and innovation actions for efficiency in the use of CRMs in wind and PV energy.	

Defence industry	Collect information about material supply chains for defence products and examine possible supply risks.		Research on materials needed for key defence capabilities to improve their resource efficiency, recycling and substitution.	
Chemicals and fertilisers			Development /optimisation of chemical processes or technologies for safe recycling or reuse of CRMs.	