FRAME

FORECASTING AND ASSESSING EUROPE'S STRATEGIC RAW MATERIALS NEEDS

DELIVERABLE: D3.1

Title: Producing a report describing the methodology used for the identification and selection process of the CRM to be included in the metallogenetic map

Work Package: WP3

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731166

GeoERA RAW MATERIALS

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Deliverable **D3.1**

Title: **Producing a report describing the methodology used for the identification and selection process of the CRM to be included in the metallogenetic map**

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GENERAL INTRODUCTION

Project FRAME (Forecasting and Assessing Europe's Strategic Raw Materials Needs) is designed to research the critical and strategic raw materials in Europe, in scenarios as described above, by employing sound strategies and a partner base spread far and wide amongst those that have some of these raw materials. Through successful teamwork, there is the expertise and knowledge base to provide a significant innovative contribution towards knowing more about the potential primary deposits, predict new target areas/deposits and to recognize the potential in secondary deposits.

WP 3 (Critical and Strategic Minerals Map) will produce a map of the current Critical Raw Materials and of the strategic raw materials for Europe, including the so-called energy and conflict minerals. WP 3 will be the backbone of the project with links to the other WP's.

Deliverable 3.1 (D3.1) aims at producing a report describing the methodology used for the identification and selection process of the CRM to be included in the metallogenetic map, linked mainly to information collected from,

- Mineralisations and deposits on land and the marine environment (linkages to all relevant WPs MINDeSEA project targeting offshore mineral resources.

- Mineralisations and deposits on land and the marine environment in which CRM make associated commodities, e.g. REE in bauxite deposits and manganese nodules; cobalt in nickel deposits and ferromanganese crusts; vanadium in iron-titanium deposits; indium and tellurium in VMS and epithermal gold deposits.

- Secondary resources, in terms of historical and modern mineral-based mining wastes (waste rocks, processing tailings, metallurgical residues) and by-products, e.g. REE in apatite concentrates related to iron extraction and red mud derived from alumina refining; indium in the waste streams of lead-zinc sulphide mining.

- Prospectivity assessments for a continental scale approach for a selection of STR and CRM materials (according to the 2017 CRM list from the European Commission, and based on the availability of data, i.e. known mineral deposits of targeted commodities). These prospectivity assessments will benefit from the latest developments in "data driven" mineral prospectivity methods that allow mapping at continental scale (i.e., CBA, or "Cell Based Association" method developed by BRGM).

Minerals and metals defined as strategic to be addressed by the FRAME project comprise the ones included in the European Critical Raw Materials (CRM) list, the minerals that are used in the Li-battery manufacturing and electric mobility society in general, the minerals needed by the decarbonitisation targets of the Energy Intensive Industries (EII), the minerals and metals which energy transition and low-carbon technologies are dependent on, and the metals required by the electronics and high-tech industry.

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The critical and strategic mineral raw materials to be included and targeted in the FRAME project are: Antimony (Sb), Gallium (Ga), Magnesium (Mg), Scandium (Sc), Baryte, Germanium (Ge), Natural graphite, Silicon metal (Si), Beryllium (Be), Hafnium (Hf), Tantalum (Ta), Bismuth (Bi), Helium (He), Niobium (Nb), Tungsten (W), Borate, HREEs-Heavy Rare Earth Elements (Dysprosium-Dy, Erbium-Er, Europium-Eu, Gadolinium-Gd, Holmium-Ho, Lutetium-Lu, Terbium-Tb, Thulium-Tm, Ytterbium-Yb, Yttrium-Y), LREEs-Light Rare Earth Elements (Cerium-Ce, Lanthanum-La, Neodymium-Nd, Praseodymium-Pr, Samarium-Sm), PGMs-Platinum Group Metals (Iridium-Ir, Palladium-Pd, Platinum-Pt, Rhodium-Rh, Ruthenium-Ru), Vanadium (V), Cobalt (Co), Indium (In), Phosphate rock, Fluorspar, Phosphorus (P), Tin (Sn), Nickel (Ni), Manganese (Mn), Copper (Cu), Lithium (Li), Selenium (Se), Tellurium (Te), Iron (Fe), Gold (Au), Silver (Ag), Chrome (Cr), Molybdenum (Mo), Rhenium (Re), Titanium (Ti), Osmium (Os).

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1. FRAME: Background and objectives

1.1 Summary

Inevitably, Europe shows a growing and accelerating consumption of mineral commodities. The question whether supply is adequate to meet demand or not cannot be answered with any certainty because secure supply is a matter of knowing the resources and the ability to exploit them with respect to sustainability. Non-energy minerals and metals underpin our modern economy and are essential for manufacturing and renewable "green" energy supply technologies. Many critical and strategic minerals and metals may be in part collected through recycling of mining related waste materials. However, because of the extent of demand, even with the important contribution from recycling, it will still be necessary to extract them from primary mineral deposits. To achieve this, increased focus must be on applying new technologies for deep exploration and mining, turning low-grade ores to exploitable resources, making smaller and complex deposits economically viable, and reducing generation of mining wastes and large tailings by converting them to exploitable resources.

Project FRAME (Forecasting and Assessing Europe's Strategic Raw Materials Needs) is designed to research the critical and strategic raw materials in Europe, in scenarios as described above, by employing sound strategies and a partner base spread far and wide amongst those that have some of these raw materials. Through successful teamwork, there is the expertise and knowledge base to provide a significant innovative contribution towards knowing more about the potential primary deposits, predict new target areas/deposits and to recognize the potential in secondary deposits.

1.2 Aims and objectives

The present project will build on previously and currently developed pan-European and national databases and expand the strategic and CRM knowledge trough a compilation of mineral potential and metallogenic areas of critical raw materials resources in Europe, focused on related metal associations on land and- marine environment. Secondary resources, in terms of historical mining wastes and potential by-products will also be considered. The mineral resources targeted will have to extend beyond the current EU CRM list and include also minerals and metals (e.g. lithium, copper, and manganese) that are strategic for the European downstream industry in the mid- and long-term perspective.

To develop metallogenic research and models at regional and deposit scales, with special attention to strategic and critical minerals for which the EU is highly dependent, in support of more efficient exploration and mining the following specific objectives need to be addressed:

• Identify and define the strategic minerals and metals in the EU that will make part of the metallogenetic map and related interpretations, focused on the current list of CRM, but considering also the strategic importance of some of those which were among the original

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candidates, such as phosphate rock, lithium, graphite, cobalt, niobium, tantalum, and others such as selenium, silver, copper, manganese, lead and iron ore. All minerals and metals collected and selected to be part of the metallogenetic map will simply go under the term CRM.

• Produce a metallogenetic map and increase the knowledge on the CRM endowments and resource potential in Europe and if possible in EU seas, based on:

o Mineralisations and deposits on land and the offshore marine environment in which CRM are the main commodities, e.g. REE minerals related to carbonatites, nepheline syenites, granites, granitic pegmatites or paleoplacers, tungsten deposits related to granites, lithium-feasible pegmatites, graphite hosted by schists.

o Mineralisations and deposits on land and the marine environment in which CRM make associated commodities, e.g. REE in bauxite deposits and manganese nodules; cobalt in nickel deposits and ferromanganese crusts; vanadium in iron-titanium deposits; indium and tellurium in VMS and epithermal gold deposits

o Secondary resources, in terms of historical and modern mineral-based mining wastes (waste rocks, processing tailings, metallurgical residues) and by-products, e.g. REE in apatite concentrates related to iron extraction and red mud derived from alumina refining; indium in the waste streams of lead-zinc sulphide mining.

• Better understanding of the ore genetic links between major deposit types and hosted critical mineral and metal associations. Understanding also the mineralizing processes in different environments, including current deep sea, and using this understanding to predict and develop new mineral deposits or deposit types. This research also involves the characterization of ores, rocks, primary and secondary deposits etc. for significant elements and minerals, whose importance has increased, and/or which represent cases where the occurrence is poorly understood or constrained. This objective and target will be interlinked and interactive with the tasks undertaken and the achievements resulted from MINDeSEA project that will address the main offshore deposit types and commodities in EU seas.

• Be able to identify conditions and processes involved in the formation of the strategic (STR) and critical raw materials (CRM)potential deposits and develop conceptual models for their formation.

• Predictive targeting based on GIS exploration tools, of high potential mineral provinces and mining districts.

• Provide potential CRM resource estimates based on the UNECE classification system in close cooperation with Mintell4EU project.

• Display and distribute the map and description on the Information platform.

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• Highlight mineral resources criticality to high-tech economy and downstream sectors.

This project will collect and act as a source of mineral information data that will support the continuous work going on in the DG-Grow, Raw Materials Supply Group and the Ad Hoc Working Group on Criticality of the EU commission.

1.3 Implementation

Forecasting and Assessing Europe's Strategic Raw Materials Needs (FRAME) specifically builds upon the following work packages:

WP 1 (Coordination/Lead) is the coordination and management work package lasting for the duration of the project. The first milestone occurs in Month 1 with a project inception meeting to commence work. WP 1 will deliver required management reports and ensure timely alignment of deliverables and milestones. WP 1 will be linked to clustering of researchers and results through the scheduling and organization of one kick-off meeting, two networking Workshops, five Consortium Meetings, three National (Regional / Local) Workshops and a final project meeting.

WP 2 (Communications, Dissemination and Exploitation) will disseminate information on the project, its progress and results to the wider community operating in the field of mineral policies and land management in the EU and beyond. WP 2 will focus on developing and implementing a comprehensive communication strategy plan that will define the project multiple stakeholders, messages and tools, as well as will implement a wide range of communications activities to fulfil its goals in accordance with the coordinator. WP 2 will receive inputs from all Work Packages for communicating their research in an understandable way to both scientific and non-scientific audiences with the help from the coordinator, who will make sure this communication works.

WP 3 (Critical and Strategic Minerals Map) will produce a map of the current Critical Raw Materials and of the strategic raw materials for Europe, namely the energy and conflict minerals. WP 3 will be the backbone of the project with links to the other WP’s.

WP 4 (Critical Raw Materials associated with phosphate deposits and associated black shales) WP 4 is dedicated to the evaluation of economic potential of igneous and sedimentary phosphate deposits (and their host black shales) in Europe, especially regarding critical and strategic raw materials (CRM). WP 4 will feed in to WP 3 and subsequently also supply data to WP 2 and coordinator will provide conditions for the communication promoting meetings and work sessions between WPs.

WP 5 (Energy Critical Elements/ECE) The main objectives of this WP are to concentrate on strategic minerals and elements, namely lithium, graphite and cobalt, which are all considered vital to current energy storage equipment and drivers of today’s technological mainstay of society. WP 5 interconnects and will feed in to WP 2 and WP 3. Another objective that the

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coordinator needs to help by promoting communication and workshops between the three raw materials specialists and the other WP specialists.

WP 6 (Conflict Minerals) Although the term "conflict minerals" is normally applied to a group of several metals as well as minerals, including the columbite-tantalite group of minerals, also known as "coltan" (from which tantalum is derived), and additionally cassiterite (tin); gold; wolframite (tungsten); or their derivatives, this WP will focus solely on tantalum and niobium, the so called indispensable twins because of their affinity to occur in similar and very specific geological settings and their important applications in electronic superconducting technology, general high-technology applications, and alloy industries. WP 6 interconnects and will feed in to WP 2 and WP 3.

WP 7 (Historical mine sites revisited). Based on the concept that today's mine dump is potentially tomorrow's mine, this WP will create a database of potential locations where some or all the strategic and critical raw materials may be found in European mine sites. Where possible this potential will be measured and evaluated. This WP will strongly link with WP 2, 3, 4, 5, 6 and 8. This link will also be promoted by WP 1 with a workshop and work sessions between WP 3, 4, 5 and 6.

WP 8 (Link to Information Platform) The cross-thematic integration of information is an important aspect to be addressed in GeoERA and therefore the objective of this WP is to provide and disseminate spatial information on the respective resources and underpinning geological data identified in the technical work packages of the project. It has a link to all WP's of the project and will provide data in a format that will allow it to be uploaded to data platforms in a future date. The WP 8 role will be of most important to make sure that data produced will be effectively introduced in the Information Platform.

1.4 Work methodology

The methodology will implement tried and tested methods of mineral exploration potential, mineral evaluation and graphical representation to be easy enough to read and be understood by the public, downstream users and decision makers.

The FRAME project's Work Packages and tasks aim at addressing and approaching the following targets:

• Continuously reinforced synergy at international level and reduced fragmentation of raw materials research and associated innovation efforts across Europe facilitating a more efficient use of natural resources, minimizing waste and improving recycling; o WP 2 and WP 3 will facilitate the generation of a holistic and common view for Europe of exploration knowledge and potential resources of Strategic Raw Materials in Europe and internationally.

  o Better understand the metallogeny and ore prospectivity of EU's primary and secondary CRM and STR resources on land and the marine environment. This will improve

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the knowledge base and thereby increase the potential for secure and sustainable supply and an expected impact in the minerals markets.

o Dissemination of an innovative approach for the better use of STR through the EU stakeholders' network.

o Promotion of better mining practices by promoting recycling and reusing of old tailings re-evaluated for strategic commodities.

• Technical solutions helping the market to enhance the exploration phase, making it more efficient and less invasive, and optimising the performance and cost of deposit exploration (e.g. re-evaluating old mines);

o Promote innovative geophysical techniques developed in projects such as SmartExploration throughout European mineral projects of strategic raw materials to reduce exploration investments and increase scarce but high value commodities.

o Increasing knowledge of Strategic and Critical Raw Materials by-products of old and ongoing mines. FRAME will focus WP 2 and WP 3 in looking for new markets for the studding commodities to bring awareness of new uses for those commodities.

• Innovative solutions for mineral exploration and development (e.g. techniques, including Data Mining, of newly created Knowledge Bases such as EU-RMKB), helping business and other stakeholders to optimize their investment;

o Modelling techniques and predictive mapping may be of high importance to develop decisions in exploration and further in exploitation will be tested in WP 4, WP 5 and WP 6 to increase exploration frontiers.

o New analytical approaches may also open frontiers to new strategic raw materials in known and unknown areas and Strategic commodities.

o Develop new viable uses/markets for strategical raw materials such as lithium, passing from ceramic industry to energy industry.

• Data and tools to facilitate the re-use and recycling of mineral-based waste;

o WP 7 tasks and achievements will contribute to better understanding of the metallogeny and ore prospectivity of EUs secondary CRMs resources on land in previously worked areas. This will improve the CRM knowledge base and thereby increase the potential for secure and sustainable supply indigenous to the EU.

o This will form a key action concerning the improvement of the pan-European critical minerals deposit and mineral-based waste database, ensuring that all available European data are current and have been checked for quality and accuracy at the

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national level, and to make them accessible in a seamless way to all users helping business and other stakeholders to optimise their investment.

- Reduction of the import dependency of Europe's industries for critical raw materials
  - WP 4, WP 5 and WP 6 will extend potential resources throughout an exploration effort of commodities such as phosphates, lithium, graphite, cobalt, niobium and tantalum, with the aim to reducing dependence from external producers.

1.5 Work package 3 objectives

To develop metallogenic research and models at regional and deposit scales as well as prospectivity maps, with special attention to strategic critical minerals for which the EU is highly dependent, in support of more efficient exploration and mining the following specific objectives need to be addressed:

- Identify and define the strategic minerals and metals that will make up part of the metallogenetic map and related interpretations, focused on the current list of CRMs, but considering also the strategic importance of some of those which were among the original candidates, such as lithium, tellurium, selenium, silver, iron ore and others. All minerals and metals collected and selected to be part of the metallogenetic map will simply go under the term CRM.

- Produce metallogenetic map and increase the knowledge on the CRM endowments and resource potential in Europe and EU seas.

- Better understanding of the ore genetic links between major deposit types and hosted critical mineral and metal associations. Understanding also the mineralizing processes in different environments, including Europe's deep-sea areas, and using this understanding to find and develop new mineral deposits or deposit types.

- Be able to identify governing conditions and processes involved in the formation of the CRM-potential deposits and develop conceptual models for their formation.

- Predictive targeting based on GIS exploration tools, of high potential mineral provinces and mining districts.

- Provide potential CRM resources estimates based on the UNECE classification system European scale prospectivity maps were produced 5 years ago by the ProMine project, using a relatively basic approach (Weight of Evidence, for most of them). They deserve to be improved using a more appropriate methodology for a continental scale approach and considering the latest (2017) CRM list. The main objective of the present task is to produce a renewed and updated set of continental scale mineral prospectivity maps, covering all EU member states and neighboring countries (Ukraine, Balkans, Norway, Switzerland, etc.), (according to the 2017 CRM list from the European Commission, and based on the availability of data, i.e. known mineral

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deposits of targeted commodities). These prospectivity assessments will benefit from the latest developments

1.6 Deliverable 3.1 objectives

Deliverable 3.1 (D3.1) aims at producing a report describing the methodology used for the identification and selection process of the CRM to be included in the metallogenetic map, linked mainly to information collected from,

• Mineralisations and deposits on land and the marine environment (linkages to all relevant WPs MINDeSEA project targeting offshore mineral resources.

• Mineralisations and deposits on land and the marine environment in which CRM make associated commodities, e.g. REE in bauxite deposits and manganese nodules; cobalt in nickel deposits and ferromanganese crusts; vanadium in iron-titanium deposits; indium and tellurium in VMS and epithermal gold deposits.

• Secondary resources, in terms of historical and modern mineral-based mining wastes (waste rocks, processing tailings, metallurgical residues) and by-products, e.g. REE in apatite concentrates related to iron extraction and red mud derived from alumina refining; indium in the waste streams of lead-zinc sulphide mining.

• Prospectivity assessments for a continental scale approach for a selection of STR and CRM materials (according to the 2017 CRM list from the European Commission, and based on the availability of data, i.e. known mineral deposits of targeted commodities). These prospectivity assessments will benefit from the latest developments in "data driven" mineral prospectivity methods that allow mapping at continental scale (i.e., CBA, or "Cell Based Association" method developed by BRGM).

2 Definition of Strategic Minerals and Metals (CRM, Battery minerals and metals, EII metals, Energy minerals and metals, Others)

Minerals and metals defined as strategic to be addressed by the FRAME project comprise the ones included in the European Critical Raw Materials (CRM) list, the minerals that are used in the Li-battery manufacturing and electric mobility society in general, the minerals needed by the decarbonitisation targets of the Energy Intensive Industries (EII), the minerals and metals which energy transition and low-carbon technologies are dependent on, and the metals required by the electronics and high-tech industry. Based on the direction given by the Industrial policy strategy, the strategic metals and minerals are necessary to,

• keep the EU industry competitive on the way to a resource efficient, low-carbon and circular economy;

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• help the EU industry to master main challenges: digitalisation, sustainability and innovation;

• strengthen domestic production and EU industrial value chains, all starting with raw materials, particularly critical raw materials (e.g. EU Battery Alliance);

• strengthen partnerships between the EU, Member States and regions;

• attract young generation and develop relevant skills, build knowledge and engage society.

2.1 Global market of CRM

Critical Raw Materials are essential for the industry and production of a broad range of equipment and devices used in everyday life. They are also fundamental for future innovations and the development of sustainable and competitive technologies. The growing consumption of the CRM generates the demand for new production of CRM commodities, both from primary (ore deposits) and secondary (mineral-based wastes) sources. Identification of potential secondary sources (via extraction and recycling technologies) becomes urgent in the light of the global scale of waste generation and demand for circular economy. However, recycling is unlikely to close the wide gap between future demand and supply by 2050, but in the long term, secondary supply from recycling will be able to meet almost 50 % of the demand, i.e., by 2100. This indicates that CRM supply will continue to be very much dependent on mining of primary mineral deposits.

Already in 2010, the EC identified several Critical Raw Materials for the European manufacturing industries and the list was extended in 2014, and then again in 2017, currently including 26 minerals and metals with natural rubber excluded (Table 1). To be qualified as critical, a raw material must be exposed to high risk regarding disruptions to its supply and be of high economic importance to major European industry sectors. Access to CRM, their resource efficient value chains and responsible sourcing are at the forefront of the EU political debate. As mentioned, recycling is part of the discussed solutions in terms of contributing to raw materials supply and better energy efficiency, but also minimising the environmental impacts. However, during the next decade, recycling, due to poorly developed extraction technologies, is unlikely to substantially contribute to the global CRM supply.

Our review focuses on mineral-based CRM, therefore natural rubber is not considered.

By the end of 2017, China remains the biggest producer of most critical raw materials for the European market, with a strong monopoly (>80% of the global total) for production of Sb, Be, Bi, LREE and HREE, magnesium and tungsten (Table 2). Other important producers are for example Brazil, Russia, the Republic of South Africa and the USA. Supplies of CRM from EU sources have been zero or very limited in the recent years (Fig.1).

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Table 1. The list of the Critical Raw Materials (excluding natural rubber), updated in 2017 by the EC (COM (2017).

2017 Critical Raw Materials				
Antimony	Cobalt	Hafnium	Magnesium	Phosphorus
Baryte	Coking coal	Helium	Natural graphite	Scandium
Beryllium	Fluorspar	HREEs	Niobium	Silicon metal
Bismuth	Gallium	Indium	PGMs	Tantalum
Borate	Germanium	LREEs	Phosphate rock	Tungsten
				Vanadium

In Table 2, the CRM global production figures include all 43 minerals and metals by considering all individual metals of the REE and PGM groups. Table 3 presents main suppliers to the EU and main sources of EU imports in years 2010-2014 (extracted from COM (2017) 490 final). Interestingly, while the big players such as China and Russia are main suppliers of CRM to Europe, the intra-EU sources are more variable and represented by several EU countries. This implies that for many EU countries, CRM production can be an important industry in the future when demand for CRM continues to increase. The main sources of supply in Table 3 include both primary (mining) and semi-primary (extraction of a by-product in another country) as well as secondary production. An example is metal production from smelters located in EU countries which themselves do not carry out mining activities, e.g. indium production in Belgium.

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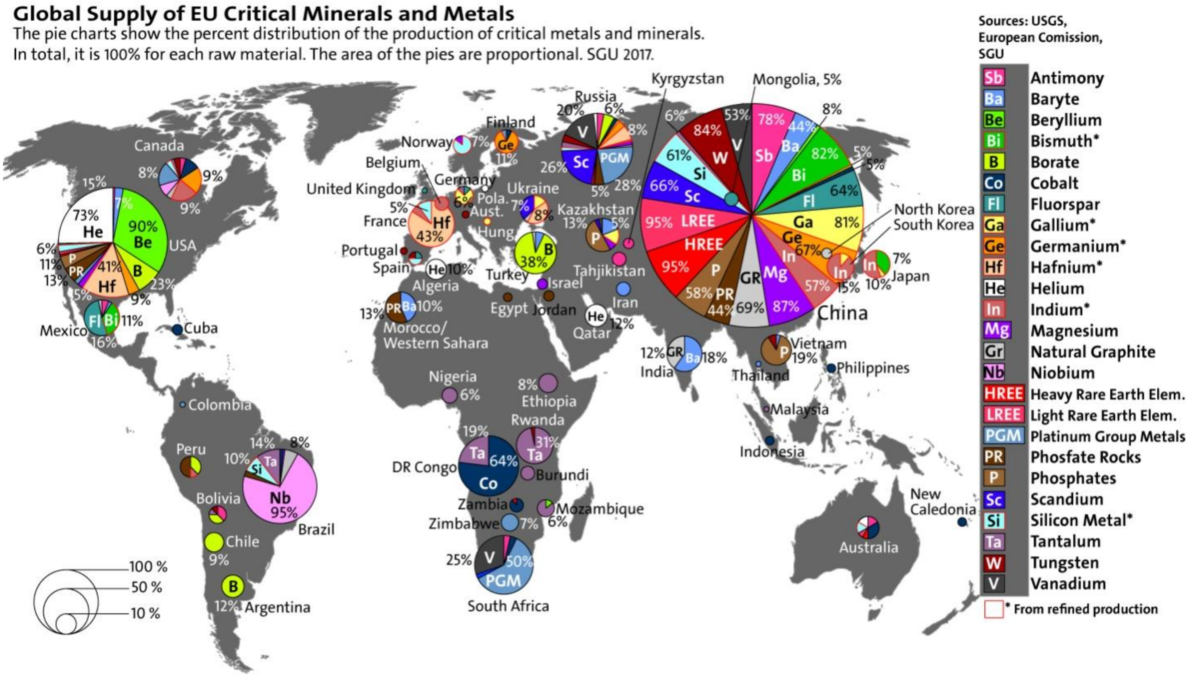

Figure 1. Countries accounting for largest share of global supply of CRMs (source: SGU).

Table 2. Global supply of the CRMs – individual materials (Study on the review of the list of Critical Raw Materials. Executive summary. 2017, p.9). Explanation of abbreviations: E = Extraction stage P = Processing stage; HREEs: Dysprosium, erbium, europium, gadolinium, holmium, lutetium, terbium, thulium, ytterbium, yttrium; LREEs: Cerium, lanthanum, neodymium, praseodymium and samarium; PGM: Iridium, palladium, platinum, rhodium, ruthenium.

no	Material	Stage	Global supplier	Share	no	Material	Stage	Global supplier	Share
1	Antimony	P	China	87%	23	Natural graphite	E	China	69%
2	Baryte	E	China	44%	24	Natural Rubber	E	Thailand	32%
3	Beryllium	E	USA	90%	25	*Neodymium*	E	China	95%
4	Bismuth	P	China	82%	26	Niobium	P	Brazil	90%
5	Borate	E	Turkey	38%	27	*Palladium*	P	Russia	46%
6	*Cerium*	E	China	95%	28	Phosphate rock	E	China	44%

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7	Cobalt	E	DRC	64%	29	Phosphorus	P	China	58%
8	*Dysprosium*	E	China	95%	30	*Platinum*	P	S. Africa	70%
9	*Erbium*	E	China	95%	31	*Praseodymium*	E	China	95%
10	*Europium*	E	China	95%	32	*Rhodium*	P	S. Africa	83%
11	Fluorspar	E	China	64%	33	*Ruthenium*	P	S. Africa	93%
12	*Gadolinium*	E	China	95%	34	*Samarium*	E	China	95%
13	Gallium*	P	China	73%	35	Scandium	P	China	66%
14	Germanium	P	China	67%	36	Silicon metal	P	China	61%
15	Hafnium	P	France	43%	37	Tantalum	E	Rwanda	31%
16	Helium	P	USA	73%	38	*Terbium*	E	China	95%
17	*Holmium*	E	China	95%	39	*Thulium*	E	China	95%
18	Indium	P	China	56%	40	Tungsten	E	China	84%
19	*Iridium*	P	S. Africa	85%	41	Vanadium	P	China	53%
20	*Lanthanum*	E	China	95%	42	*Ytterbium*	E	China	95%
21	*Lutetium*	E	China	95%	43	*Yttrium*	E	China	95%
22	Magnesium	P	China	87%					

Table 3. List of CRM and their main importers and main sources of the EU supply. EU and associated countries (Norway and Switzerland) are marked in bold (from COM (2017) 490 final).

CRM	Main importers to the EU (av.2010-2014)	Main sources of the EU supply (av.2010-2014)	End-of Life recycling input rate (the ratio of recycling from old scrap to EU demand)
Antimony	China (90%) Vietnam (4%)	China (90%) Vietnam (4%)	28%
Baryte	China (53%) Morocco (37%)	China (34%) Morocco (30%)	1%

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CRM	Main importers to the EU (av.2010-2014)	Main sources of the EU supply (av.2010-2014)	End-of Life recycling input rate (the ratio of recycling from old scrap to EU demand)
	Turkey (7%)	Germany (8%) Turkey (6%) United Kingdom (5%) Another EU (4%)	
Beryllium	n/a	n/a	0%
Bismuth	China (84%)	China (84%)	1%
Borate	Turkey (98%)	Turkey (98%)	0%
Cobalt	Russia (91%) Democratic Republic of Congo (7%)	Finland (66%) Russia (31%)	0%
Fluorspar	Mexico (38%) China (17%) South Africa (15%) Namibia (12%) Kenya (9%)	Mexico (27%) Spain (13%) China (12%) South Africa (11%) Namibia (9%) Kenya (7%) Germany (5%) Bulgaria (4%) United Kingdom (4%) Another EU (1%)	1%
Gallium	China (53%)	China (36%)	0%

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CRM	Main importers to the EU (av.2010-2014)	Main sources of the EU supply (av.2010-2014)	End-of Life recycling input rate (the ratio of recycling from old scrap to EU demand)
	United States (11%) Ukraine (9%) South Korea (8%)	Germany (27%) United States (8%) Ukraine (6%) South Korea (5%) Hungary (5%)	
Germanium	China (60%) Russia (17%) United States (16%)	China (43%) Finland (28%) Russia (12%) United States (12%)	2%
Hafnium	Canada (67%) China (33%)	France (71%) Canada (19%) China (10%)	1%
Helium	United States (53%) Algeria (29%) Qatar (8%) Russia (8%)	United States (51%) Algeria (29%) Qatar (8%) Russia (7%) Poland (3%)	1%
Indium	China (41%) Kazakstan (19%) South Korea (11%) Hong Kong (8%)	China (28%) Belgium (19%) Kazakhstan (13%) France (11%) South Korea (8%) Hong Kong (6%)	0%

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CRM	Main importers to the EU (av.2010-2014)	Main sources of the EU supply (av.2010-2014)	End-of Life recycling input rate (the ratio of recycling from old scrap to EU demand)
Magnesium	China (94%)	China (94%)	9%
Natural graphite	China (63%) Brazil (13%) Norway (7%)	China (63%) Brazil (13%) Norway (7%) EU (< 1%)	3%
Niobium	Brazil (71%) Canada (13%)	Brazil (71%) Canada (13%)	0.3%
Phosphate rock	Morocco (31%) Russia (18%) Syria (12%) Algeria (12%)	Morocco (28%) Russia (16%) Syria (11%) Algeria (10%) EU – Finland (12%)	17%
Phosphorus	Kazakhstan (77%) China (14%) Vietnam (8%)	Kazakhstan (77%) China (14%) Vietnam (8%)	0%
Scandium	Russia (67%) Kazakhstan (33%)	Russia (67%) Kazakhstan (33%)	0%
Silicon metal	Norway (35%) Brazil (18%) China (18%)	Norway (23%) France (19%) Brazil (12%) China (12%) Spain (9%)	0%

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CRM	Main importers to the EU (av.2010-2014)	Main sources of the EU supply (av.2010-2014)	End-of Life recycling input rate (the ratio of recycling from old scrap to EU demand)
		Germany (5%)	
Tantalum	Nigeria (81%) Rwanda (14%) China (5%)	Nigeria (81%) Rwanda (14%) China (5%)	1%
Tungsten	Russia (84%) Bolivia (5%) Vietnam (5%)	Russia (50%) Portugal (17%) Spain (15%) Austria (8%)	42%
Vanadium	Russia (71%) China (13%) South Africa (13%)	Russia (60%) China (11%) South Africa (10%) Belgium (9%) United Kingdom (3%) Netherlands (2%) Germany (2%) Another EU (0.5%)	44%
PGM	Switzerland (34%) South Africa (31%) United States (21%) Russia (8%)	Switzerland (34%) South Africa (31%) United States (21%) Russia (8%)	14%
HREEs	China (40%) USA (34%) Russia (25%)	China (40%) USA (34%) Russia (25%)	8%

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CRM	Main importers to the EU (av.2010-2014)	Main sources of the EU supply (av.2010-2014)	End-of Life recycling input rate (the ratio of recycling from old scrap to EU demand)
LREEs	China (40%) USA (34%) Russia (25%)	China (40%) USA (34%) Russia (25%)	3%

2.2 Applications and uses

Uses and applications have been collected according to the updated list of CRM and CRM Factsheets published by EU in June 2017, e.g. baryte has been included while chromium has been excluded. Of the CRM presently included in this classification, a majority are metals with several well-specified uses technologies and applications.

For a metal like **antimony**, while important uses include alloys, batteries, glasses, ceramics, and plastics, the overall biggest range of applications is within the production of fire (flame) retardants. In this specific case, a large part goes into fire-retardation of plastics, but also into a variable range of other products such as textiles, paints and rubbers, which cannot be readily recycled.

The mineral **barite**, barium sulphate, is extensively used in the oil and gas drillings industry and is therefore dissipated and cannot be recycled. Barite used for fillers, ceramics, plastics and paint, have more potential in this sense, but are presently considered not to be easily recyclable.

Beryllium is mainly used for alloys and in ceramics, but is also utilised in its pure form, as beryllium metal for specialised high-tech applications. While products can be expected to have a long life, some of them, including those employed for military technology, are not returned to the industry. On the other hand, the aerospace industry can be a major source for recycling.

The metal **bismuth** is used in a broad range of products, dominated by solders and alloys, and various pharmaceutical products, as well as electronics and coatings. As a majority of e.g. pharmaceutical applications are dissipative, bismuth cannot be recycled. In the alloys and related products, it is mostly a minor metal, and is not recycled.

Borates, boron-oxygen compounds, comprise a broad suite of minerals which may also include borosilicates (despite being included in the grouping "borates"), that are used to produce different boron compounds, chiefly boric acid. The boron compounds are used in a great number of applications including glass and fiber glass, household products, ceramics, and nutrients for

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agriculture. Because of the nature of these applications, boron/borate recycling is mainly prevented.

The metal **cobalt** has a wide range of uses including pigments but is increasingly used in high-tech applications for battery technology, catalysts and various alloys and hard materials. While glass and other materials pigmented by cobalt cannot be recycled, spent catalysts, batteries and high-cobalt metal scraps can be successfully recycled.

Fluorite (or fluorspar) is a calcium-fluoride mineral, and used mainly to produce fluorine compounds, such as hydrofluoric acid. Fluorine compounds are used in the production of fluoropolymers as well as fluorochemicals for air-conditioning, refrigeration, pharmaceutical and allied applications. Large amounts of fluorite are also used in the production of fluxing materials used in metal and ceramics production, and some still go into the production of specialised optical products. Because of the consumption of the fluorite or fluorine-rich chemicals utilised in these processes, fluorite cannot be said to be recyclable.

Gallium and **germanium** are two rare metals that are primarily used for their electrical properties, particularly when used in semiconductors in the wider sense, in a range of applications at the core of modern high-tech electronics, in photovoltaics, fiber optics, as well as modern LED technology. Depending on product, recycling can be feasible to supply a significant component back into production.

Hafnium is a rare metal with a limited, yet important range of applications, which comprise super alloys and nuclear reactor technology, as well as in high-refractory materials. Because of the limitations from its applications, such as radioactive contamination or low contents in special alloys, hafnium is presently not recycled.

Another rare metal is **indium**. It has gone from relative obscurity to wide-ranging use in the form of different chemical compounds in, particularly, the semiconductor, photovoltaics, and flat screen technologies. Indium is also used in solders and alloys. Depending on product types and regions, it can be successfully recycled from diverse, higher-grade scrap sources, such as indium-tin oxide film products.

Magnesium is a light metal that does not, however, occur naturally in its pure state but in several different minerals. Major applications are alloys and structural applications, because of its high strength to weight ratio, as well as for desulphurisation in iron and steel production. Because of its many applications in which it occurs in comparatively high contents in simple materials, magnesium is amenable to recycling.

Natural graphite is the most common mineral form of carbon on Earth. It is used in simple products such as pencils, but most importantly in steel making and foundries, because of its refractory properties, and for its use in decarburising. It is also extensively used in lubricants and

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friction products, and increasingly so, in battery technology, as well as high-tech applications of the refined end-product graphene. Due to its application types, most graphite cannot be recycled.

Niobium is a rare, hard and refractory metal, which is used in high-strength alloy steels, superconducting magnets, hard materials, and special glass coatings. Presently, despite the overall possibility to recover niobium from special steel scrap, the actual rate of recycling is low to non-existent.

The **platinum group metals (PGM)** are among the least abundant of the metals in the continental crust. They, and group members platinum, palladium and rhodium, which are most widely used, are valuable precious metals as well as industry metals of major importance. The absolute largest application is in automotive catalysts, in addition to petroleum refining, electrical products and jewelry products. As the PGM are high-value metals that are utilised in often very specific applications, the potential for recycling is very good, and is also steadily increasing, except for jewelry.

Phosphate rocks supply one of the most vital components to the production of fertilisers, phosphorous. The importance of fertilisers for modern agriculture cannot be overstated, and despite the broad range of countries with suitable geology for phosphate production, supply is threatened in a growing world. Due to the nature of its main uses, phosphates and phosphate rocks cannot be recycled yet, however, alternative uses of waste streams from biological/vegetable sources may become increasingly functional.

The **rare earth elements (REE)** are a group of metals consisting of the 15 lanthanoids together with yttrium and scandium. They play an increasingly important role in a very broad range of technological applications, ranging from nuclear energy, via green or low-carbon energy production, research, consumer and military electronics as well as the automotive industries. Because of their intrinsically chemical similarities they are very difficult to purify, and they are also used in relatively small total quantities in many applications, which combine to make recycling problematic. Specialised products with higher contents such as magnets and some alloys may however be more functional to recover.

Silicon is the most common metal in the crust of the Earth. It is used extensively in the metallurgical and chemical industries, with the latter producing numerous silica compounds used in insulating materials, whereas electrical grade silicon metal is used in the electronics industry for applications such as semiconductors and photovoltaics. Much silicon is presently not recycled, yet good potential lies in the recovery of silicon from alloys and semiconductor industry refuse.

The rare metal **tantalum** is used primarily in electronic applications, such as cell phones, in high-tech alloys, sputtering technology, and hard materials such as cutting tools. The present status of recycling is very low, but there is potential in the recovery from specialised alloy and tool products as well as electronics.

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Tungsten is another relatively rare metal, with highly specialised applications, particularly within old-style incandescent lamp manufacture, special alloys and hard materials, as well as catalysts and military applications. Due to its characteristics, specific applications and relatively high value, tungsten is very amenable to recycling.

Vanadium is a moderately rare metal, especially in the form of commercially exploitable deposits. It is very widely used as an alloying metal and catalyst. The abundant use of it in alloys, including tool steel, means that it is very amenable to recycling.

2.3 Battery minerals

The introduction of electromobility in our modern society causes major challenges in terms of new high-tech components and related mineral raw materials supplies needed for the electric vehicle (EV) manufacturing. In this respect, due to the unmatchable combination of higher energy and power density, and the viability of large-scale energy storage, Li-batteries show an unbeatable performance, and have therefore a central and crucial role in electric car-making industries. According to IEA and UN Paris Declaration, the number of electric vehicles is expected to reach 10 million by 2020 and 100 million by 2030 from the current 2 million, to achieve the targets for greenhouse gas emissions. To power these vehicles, millions of new battery packs will need to be manufactured. The Li-ion battery market is expected to grow at a 21.7% rate annually in terms of the actual energy capacity required. Production amounted to 100 GWh in 2015 but will increase to 140 GWh by 2020 and to 215 GWh by 2025, according to Avicenna Energy data. Based on the forecast of German National Platform for Electromobility the Li-ion automotive batteries market will grow even quicker, reaching from 150 (conservative scenario) up to 400 GWh (optimistic scenario) in 2025.

Each Li-ion cell contains three parts: the anode mainly made of natural or synthetic graphite, the electrolyte consisting of Lithium salts and the cathode made of metals such as cobalt (Co), nickel (Ni), copper (Cu), aluminium (Al) and manganese (Mn) (Fig. 2). Given the upward trend of electrification, responsible sourcing and uninterrupted supply of particularly Li, Co and graphite will become more significant for the development of sustainable Li-battery manufacturing and EV industries in the EU.

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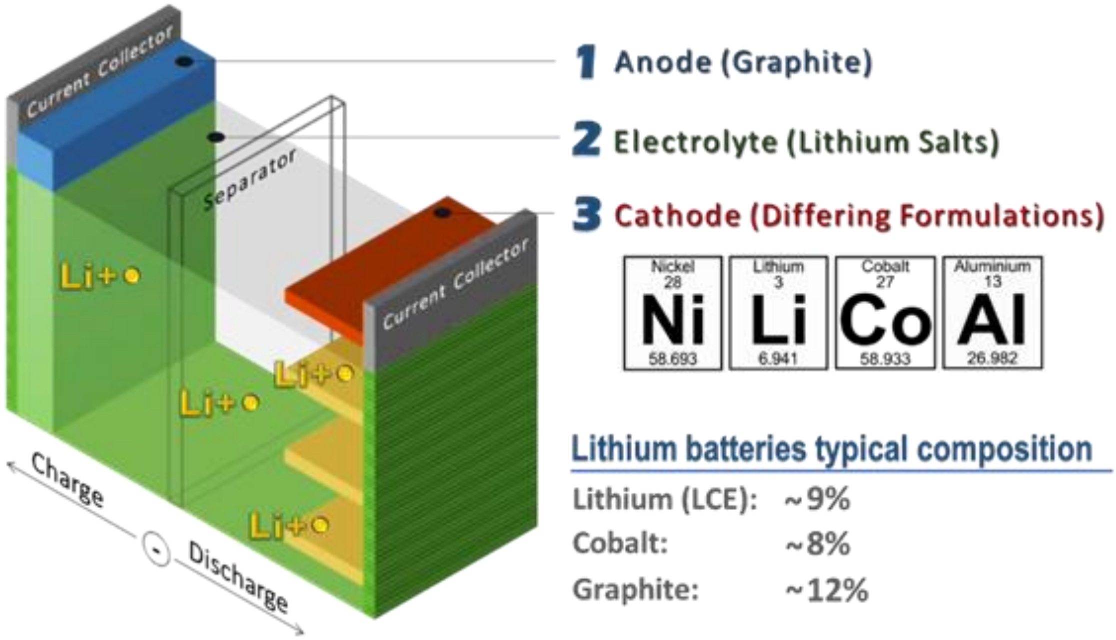

Fig.2: Each Li-ion cell needs metals such as cobalt (Co), nickel (Ni), copper (Cu), aluminium (Al) and manganese (Mn)

Without sufficient supply of the minerals and metals needed, technological development and the move towards a less carbon intensive society will be slowed. The risk of running into bottlenecks in raw material supply is increasing because demand is growing faster than production capacity. Europe's geology hosts a variety of mineral deposits of Li, Co and natural graphite (EuroGeoSurveys, 2017), of which some give rise to active operating mines and others constitute exploration targets for projects at different stages of development (Raw Materials Scoreboard, 2017, European Commission).

Although Mn, Cu, Ni and Al are important for Li-ion batteries as well, they are also more abundant metals from numerous source countries and less impacted by the electromobility development. In contrast, Li supply is dominated by the so called "Lithium Triangle" (Argentina, Chile and Bolivia) possessing 74% of the world resources. Likewise, more than 65% of flake graphite is mined in China under very poor environmental and labour practices, while around 60% of the world Co production comes from the DRC (Fig.3), a country that is extremely politically unstable with deeply-rooted corruption, child labour and unethical mining operations.

Future demand resulting from increased battery production and high-tech applications are projected to be dramatic. As sales of EVs ramp up, so will the need for a spectrum of metals that are used to make batteries. Automotive demand for Li is set to climb 35% each year through 2021, Co will increase roughly by 450% from this year to 2025, whereas graphite demand is expected to increase by 50% by 2020 (Fig.4).

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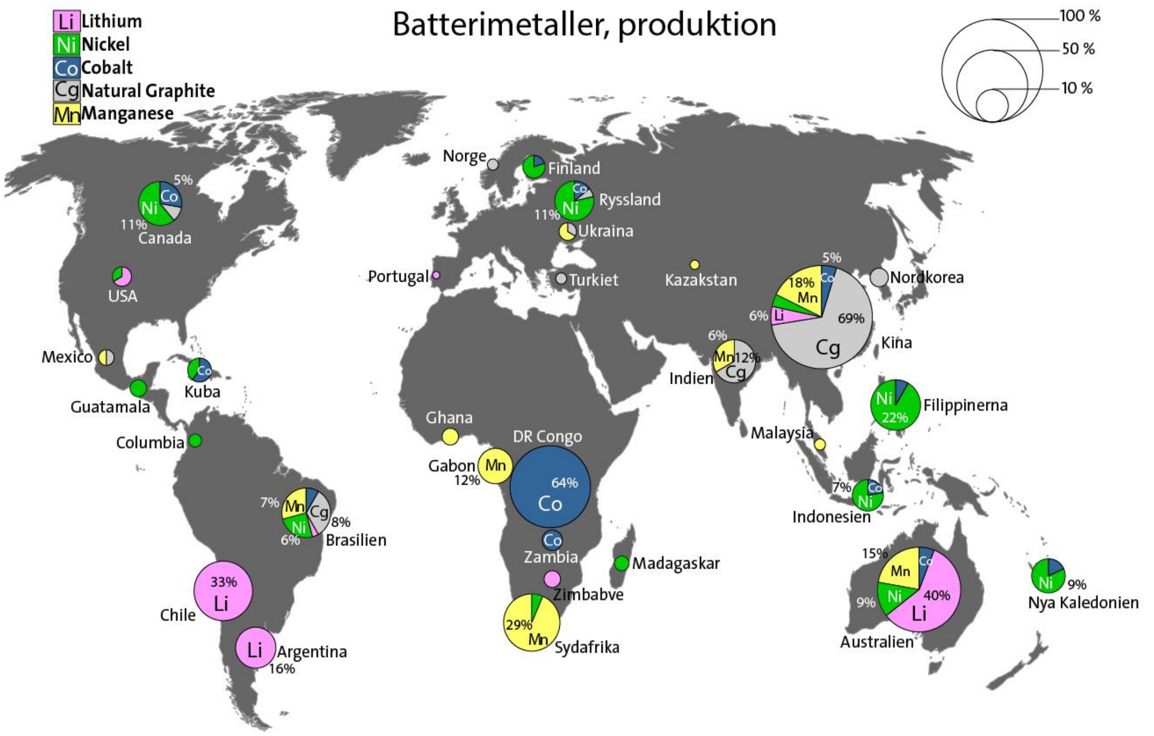

Fig.3: The EU battery minerals supply is mainly import dependent on resources mined and processed in China, South America, Australia and Africa (Source: SGU).

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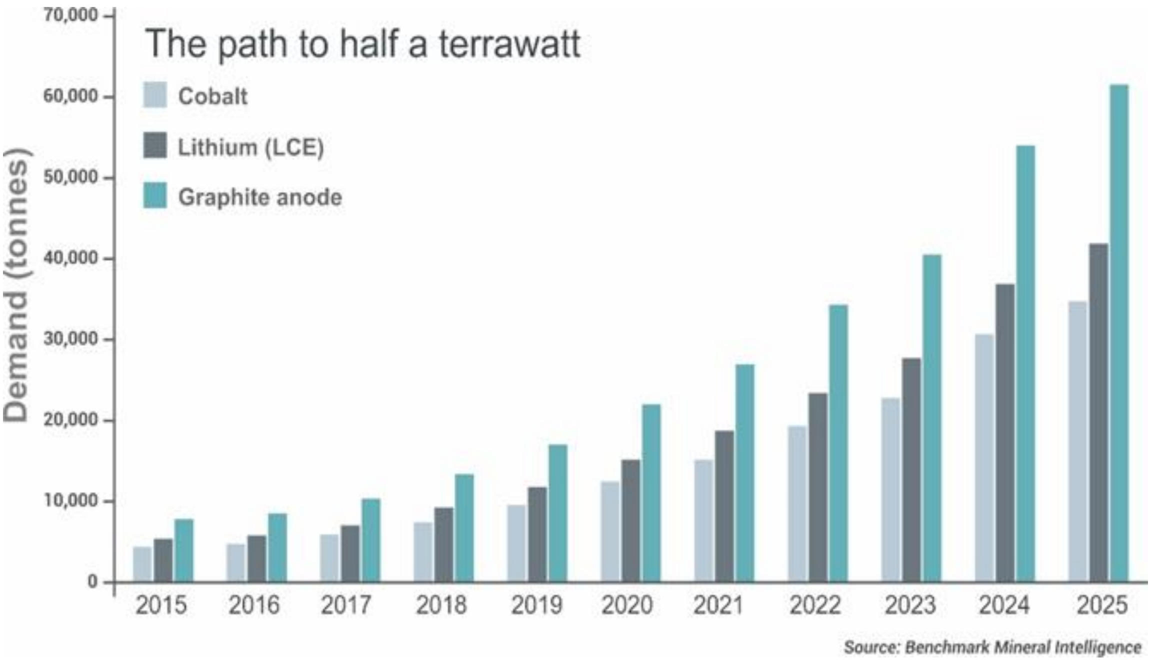

Fig.4: The demand of battery minerals is expected to grow dramatically during coming years

Apple is seeking contracts to secure several thousand metric tons of Co per year for 5 years or longer, finding itself in competition with carmakers and battery producers to lock up Co supplies. Similarly, companies including BMW, Volkswagen and Samsung are racing to sign multiyear Co contracts to ensure they have sufficient Co supplies to meet the ambitious targets for EV production.

It is thus clear that escalating battery demand is putting pressure on the Li-ion supply chain. To efficiently address the fast-growing needs of the EU battery manufacturing (Fig.5) electric vehicle industry the issue of the battery raw materials supply should be addressed in a holistic approach by providing the proper solutions for the whole value chain; from mineral exploration and mining to ore dressing and processing of Li-pegmatite, flake graphite, and Cu-Co, Ni-Co and Ni-Cu sulphide deposits.

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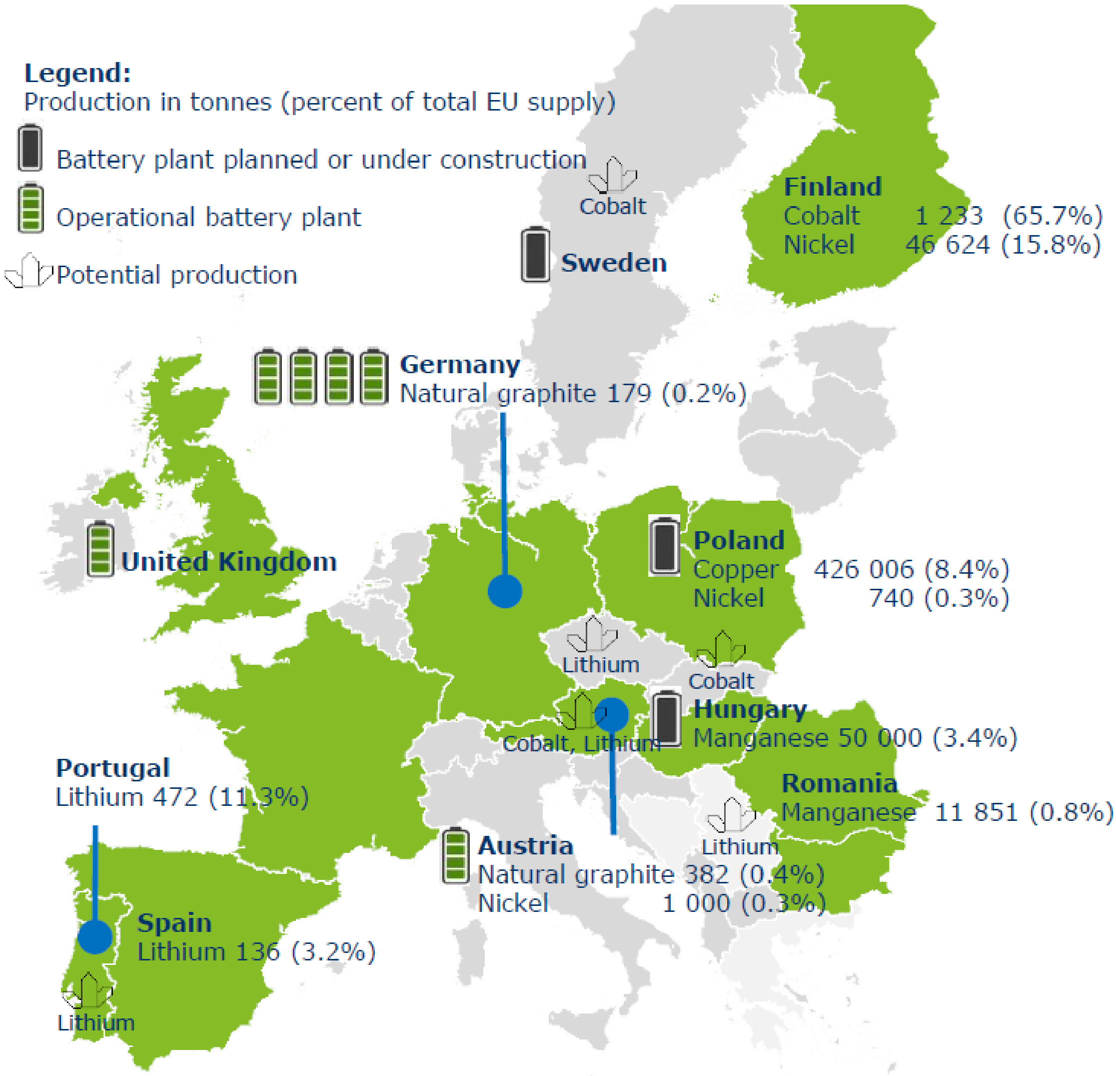

Fig.5: The planning of new battery plants underway in Europe will increase the need for mineable indigenous sources of lithium, graphite, cobalt, nickel and manganese (Source: Study on the review of the list of Critical Raw Materials, Critical Raw Materials Factsheets, June 2017).

2.4 Energy transition and related energy intensive industries

Energy Intensive Industries realise the need for a transition to low-carbon and circular economy to stay competitive. For this to happen they should work together to assess the implications (demand for electricity, raw materials etc.) and to develop value chain partnerships based on the sustainable supply of specific mineral resources (Fig.6), as well as to ensure a stable and predictable regulatory framework, including climate and energy policies. This way steelmaking will for example target new less carbon-intensive methods.

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Fig. 6: Energy transition technologies will require the supply of strategic minerals towards a low-carbon society.

2.5 FRAME strategic minerals and metals compiled

Following up the criticality aspects, and leading technology and industrial applications of raw materials issued above, those to be considered and drafted as strategic minerals for the FRAME project are compiled and listed in Table 4.

3 Data collection

Data and information will be collected from strategic and critical raw materials mineral deposits and systems including any available geological knowledge and developed concepts, classification deposit types involved, estimation of the resources using the UNCF system, assessment of the exploitation potential and generation of new exploration targets in poorly explored and/or underexplored areas with respect to all kind strategic minerals mentioned above. Pan-European data and information on for example CRM and battery minerals, including Co, Li and graphite, but also Cu, Ni, Al and Mn will be compiled and updated. Data currently residing in the Minerals4EU platform, managed and operated by EuroGeoSurveys, will be supplemented by other existing mineral databases and FRAME'S own harvesting efforts, based mainly on the methodology and the instructions provided by the MINTELL project. All compiled data will be fed into the RMIS hosted by JRC. Bedrock and structural geology data, and drillcore information, along with geophysical and geochemical signatures, will also be considered, when possible, to facilitate the

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approach of potential strategic mineral exploration targets, e.g. of each of the battery mineral systems identified.

Tab. 4: List drafting and compiling the FRAME strategic minerals and metals

Strategic Minerals and Metals*			
Critical Raw Materials (2017 EU-list excluding Natural Rubber)	**Battery Minerals and Metals**	**Energy Transition & Intensive Industries Metals**	**High-Tech Metals (Catalysts, Alloys, Glass, Ceramics, Steel)**
Antimony (Sb)	Lithium (Li)	Lithium (Li)	Gold (Au)
Gallium (Ga)	Cobalt (Co)	Cobalt (Co)	Silver (Ag)
Magnesium (Mg)	Manganese (Mn)	Gallium (Ga)	Cerium (Ce),
Scandium (Sc)	Copper (Cu)	Germanium (Ge)	Chromium (Cr)
Baryte	Nickel (Ni)	Indium (In)	Molybdenum (Mo)
Germanium (Ge)	Vanadium (V)	Platinum (Pt)	Rhenium (Re)
Natural graphite	Aluminium (Al)	Iridium (Ir)	Selenium (Se)
Silicon metal (Si)	Magnesium (Mg)	Vanadium (V)	Titanium (Ti)
Beryllium (Be)	REE	Silicon metal (Si)	Osmium (Os)
Hafnium (Hf)	Silicon metal (Si)	Europium (Eu),	
Tantalum (Ta)	Tin (Sn)	Gadolinium (Gd)	
Bismuth (Bi)	Natural Graphite	Terbium(Tb)	
Helium (He)		Samarium (Sm)	
Niobium (Nb)		Ytterbium (Yb)	
Tungsten (W)		Yttrium (Y)	
Borate		Antimony (Sb)	
HREEs-Heavy Rare Earth Elements		Tin (Sn)	
(Dysprosium-Dy, Erbium-Er, Europium-Eu, Gadolinium-Gd, Holmium-Ho, Lutetium-Lu, Terbium-		Selenium (Se)	
		Tellurium (Te)	
		Dysprosium (Dy)	

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Tb, Thulium-Tm, Ytterbium-Yb, Yttrium-Y) LREEs-Light Rare Earth Elements *(Cerium-Ce, Lanthanum-La, Neodymium-Nd, Praseodymium-Pr, Samarium-Sm)* PGMs-Platinum Group Metals *(Iridium-Ir, Palladium-Pd, Platinum-Pt, Rhodium-Rh, Ruthenium-Ru)* *Vanadium (V)* Cobalt (Co) Indium (In) Phosphate rock Fluorspar Phosphorus (P)		Neodymium (Nd) Praseodymium (Pr) Boron (B) Iron (Fe) Aluminium (Al) Niobium (Nb)	

* *All CRM along with Sn, Ni, Al, Mn, Cu, Li, Se, Te, Fe, Au, Ag, Cr, Mo, Re, Ti, Os make the list of the FRAME strategic minerals and metals.*

3.1. Past & ongoing EU projects

Several EU projects addressed objectives and issues related to CRM and other strategic minerals at the various levels of details (see Fig. 7 and Table 5).

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Fig. 7. EU funded projects addressing strategic mineral resources with involvement of Geological Surveys in respective partnerships.

The information available from their websites varies a lot. So far, the only digital data platform on strategic minerals, including CRM, battery minerals and others, from both primary and secondary resources is provided by the ProMine project. However, the data has not been updated since the project was finished. Some updated aggregated information was published in the Minerals Yearbook drafted during the Minerals4EU project. A new digital database platform on mining wastes is underway through PROSUM project and is planned to be delivered by the end of 2018 to be hosted and operated by the Minerals4EU permanent body. This new operational service will provide data and information on arisings, stocks, flows and treatment of mining wastes.

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Table 5. EU projects (completed and on-going projects addressing the CRM from mineral-based waste).

Project	Full name	Status	Links	Strategic mineral relevance	Digital data platform
PROMINE	Nano-particle products from new mineral resources in Europe	Finished project	http://promine.gtk.fi	yes	yes
MINERALS4EU	Minerals Intelligence Network for Europe	Finished project	http://www.minerals4eu.eu/, http://minerals4eu.brgm-rec.fr/	yes	yes (incomplete, not all countries represented)
EuroGeoSource	EuroGeoSource	Finished project	http://www.eurogeosource.eu	partly	not operational for the moment
EURARE	EURARE (Development of a sustainable exploitation scheme for Europe's Rare Earth ore deposits')	Finished project	http://www.eurare.eu/	yes	Integrated Knowledge Management System (IKMS) for REE resources in Europe.
EGDI	European Geological Data Infrastructure	on-going	http://www.europe-geology.eu/	yes	yes
MINVENTORY	The Minventory metadata portal Minventory Portal	Finished project	http://www.minventory.eu/ https://ec.europa.eu/jrc/en/scientific-tool/minventory	partly	Yes Final Report: Minventory - EU raw materials statistics on resources and reserves

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GeoERA RAW MATERIALS

Project	Full name	Status	Links	Strategic mineral relevance	Digital data platform
ERA-MIN	ERA-NET Cofund on Raw Materials (ERA-MIN 2)	on-going	https://www.era-min.eu/	yes	no
PROSUM	ProSUM – Prospecting Secondary raw materials from the Urban Mine and Mining waste	Finished project	http://www.prosumproject.eu/	yes	yes
MICA	Mineral Intelligence Capacity Analysis	on-going	http://www.mica-project.eu/	yes	yes (under construction)
Smart Ground	Smart data collection and integration platform to enhance availability and accessibility of data and information in the EU territory on secondary raw materials.	on-going	http://www.smart-ground.eu/	yes	yes (under construction)
Min-Guide	Minerals Policy Guide	on-going	http://www.min-guide.eu/about/overview	yes	no

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Project	Full name	Status	Links	Strategic mineral relevance	Digital data platform
SCRREEN	Solutions for Critical Raw materials-a European Expert Network	on-going	http://scrreen.eu/	yes	Preliminary version (prototype) of the EUCRMKDP (EUROPEAN UNION CRITICAL RAW MATERIALS KNOWLEDGE DATA PLATFORM)

ProMine project (http://promine.gtk.fi/ ; http://ptrarc.gtk.fi/ProMine/default.aspx)

The purpose of the ProMine project (2009-2013) was to enhance the overall production chain of minerals and metals in Europe. A major objective of the ProMine was to stimulate the extractive industry to deliver new products to manufacturing industry. ProMine produced a pan-European GIS based resources and modelling system for all potential metallic and non-metallic mineral resources (known and predicted) within the EU. The project produced INSPIRE compliant data, a geospatial data portal, web map services, a web feature service and reports. ProMine geospatial data portal with the map viewer provides point data with the description of the CRM and other strategic minerals concentrations in various types of deposits, including mining wastes. (data from the PROMINE portal is also accessible via EGDI portal).

The ProMine delivered a database containing the known and predicted metalliferous and non-metalliferous resources, which together define the strategic reserves (including strategic minerals) of the EU. Among other tasks, the project tried to calculate the volumes of potentially strategic metals (e.g. cobalt, niobium, vanadium, antimony, platinum group elements and REE) and minerals that are currently not largely extracted in Europe.

As a matter of fact, it was the first ever delivery of the occurrences of critical mineral resources in Europe, at the request of the Commission, thus demonstrating the usefulness of a European

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wide mineral resource assessment. The ProMine investigated geological mineral resource potential modelling across Europe, where some of the CRM were included, e.g. new strategic and 'green 'commodities such as Ga, Ge, In, Li, Nb, Ti, Ta, PGE and REE. Assessment of secondary resources in combination with metalliferous ores, assessment of valuable mining and metallurgical residues were some of the tasks.

Minerals4EU (http://www.minerals4eu.eu/)

The Minerals4EU project was designed to meet the recommendations of the Raw Materials Initiative to develop an EU Mineral intelligence network structure delivering a web portal, a European Minerals Yearbook and foresight studies. The Minerals4EU project was built around an INSPIRE compliant platform that enables EU geological surveys and other relevant parties to share mineral information and knowledge, and stakeholders to find, view and acquire standardized and harmonized mineral resources and mineral statistics data.

The main task of the project was to provide a minerals information and intelligence operational service, incorporating links to existing projects, relevant databases and auxiliary datasets of Geological Surveys and other relevant institutions consisting of mineral data from primary and secondary resources on land and the sea-floor.

The Minerals Yearbook (Fig.8) is the most comprehensive compilation of publicly-available European minerals information. Almost all CRM and other strategic minerals are listed in the Yearbook if searched after Commodity for primary minerals.

The map viewer (http://minerals4eu.brgm-rec.fr/minerals4EU/) provides similar information as the Minerals Yearbook. The EU-MKDP (Minerals Knowledge Data Platform;Fig.9) is set up to provide a simplified and user-friendly access to all available and new data related to mineral resources from national geological surveys, scientific institutes and universities, relevant industries and professional organizations, as well as from former European projects such as ProMine (information on both mineral deposits and anthropogenic concentrations resulting from mining and downstream activities) and EuroGeoSource (http://www.eurogeosource.eu/; information on energy and mineral resources, extraction locations, production, reserves). The system is also designed to accommodate and manage semi- and non-structured data (e.g., syntheses and statistics in the form of graph charts, time-series related to exploration and primary reserves and resources, secondary resources, exploitation technologies including ore beneficiation, extraction technologies, end- product development and waste management practices, European market survey and raw material demand). These data, semantically harmonized using common terminology are delivered through INSPIRE/OGC compliant web services.

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The information on primary and secondary sources of raw materials, together with expertise, will form the three main blocks of the EURMKB (https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/knowledge-base_en):

- Data collection - data and information will be collected from different sources, such as EUROSTAT, the Joint Research Centre, agencies (such as geological surveys) in EU countries, other national and international organisations, European projects and programmes, and industry.
- Maintenance - the EURMKB will apply EU and global standards, maintain and update data and information, and make it available to the public through the internet and publications.
- Expertise - selected parts of the data and information will be analysed and reported to the public as expertise, for example Material flow analysis (MFA) for metals. Spatial data will be available in an INSPIRE compliant way, as well as in 3D when appropriate.

Following the huge success of the European Intelligence Network on the Supply of Raw Materials (Minerals4EU) project, the “Minerals Intelligence Infrastructure for Europe” has been legally registered under the form of a Foundation on March 2016. The non-profit Minerals4EU Foundation overall scope is to provide a one-stop-shop to official and verified data, information and knowledge on mineral resources, and to act as contact point through which stakeholders can easily and transparently access its products and expertise. Among its main services, the Foundation will coordinate the development of the European Union Mineral Resources Knowledge Base infrastructure, in support to European Union affairs, policies and action programmes, and will provide the best available EU expertise and information based on the knowledge of its Members, composing the European Minerals Intelligence Network. Moreover, the Minerals4EU Foundation will respond to specific requests from the European Union or will formulate proposals for actions of interest to the EU. The Foundation is governed by a Management Board overseeing the whole management of the organization and composed of both private and public-sector key EU stakeholders representing the whole mineral resources value chain. It is expected that the services put in place will ultimately serve to boost EU economy and competitiveness in the field of Raw Materials.

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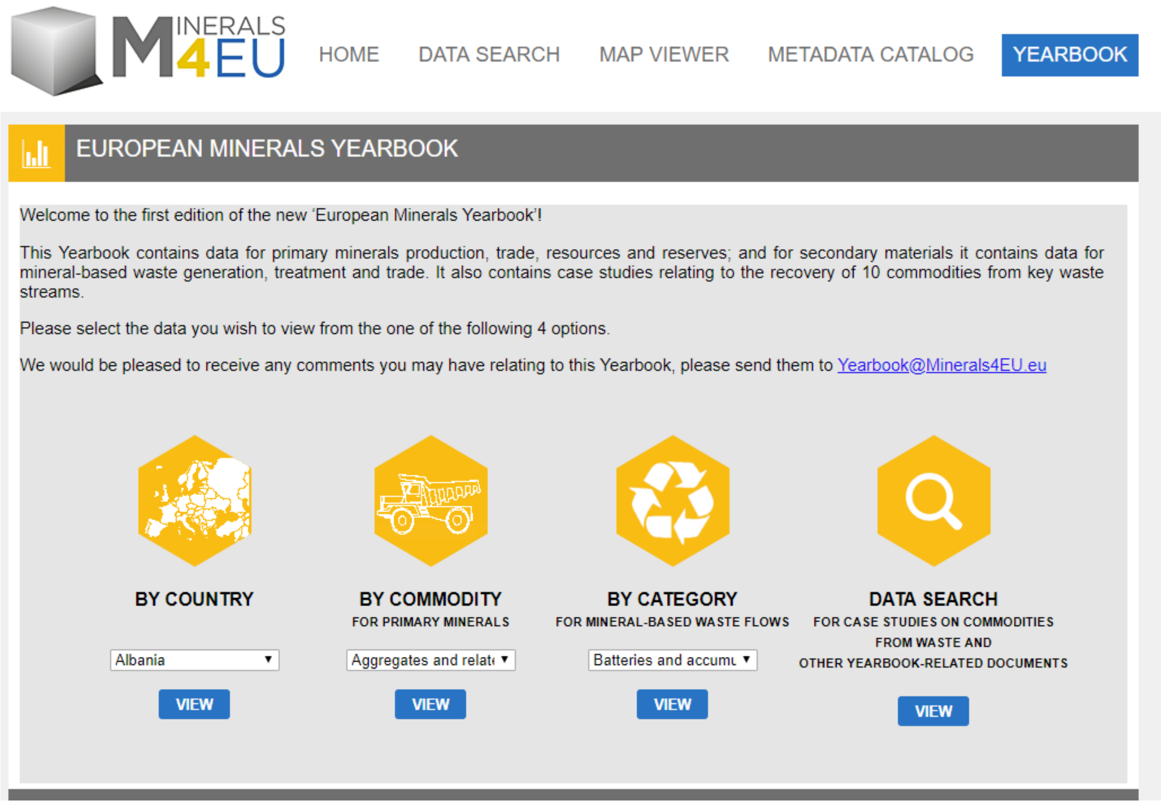

Fig.8: The Minerals Yearbook provides comprehensive compilation of publicly-available European minerals information.

EURARE (http://www.eurare.eu/)

EURARE was a project, funded within the FP7 framework by the European Commission, for the 'Development of a sustainable exploitation scheme for Europe's Rare Earth ore deposits'. EURARE is thus entirely focused on the so-called rare earth elements (REE), this group of metals considered very strategic and critical for which Europe is wholly dependent on imports. The main goal of the EURARE project was to set the basis for the development of a European REE industry that will safeguard the uninterrupted supply of REE raw materials and products crucial for the EU economy industrial sectors, such as automotive, electronics, machinery and chemicals, in a sustainable, economically viable and environmentally friendly way.

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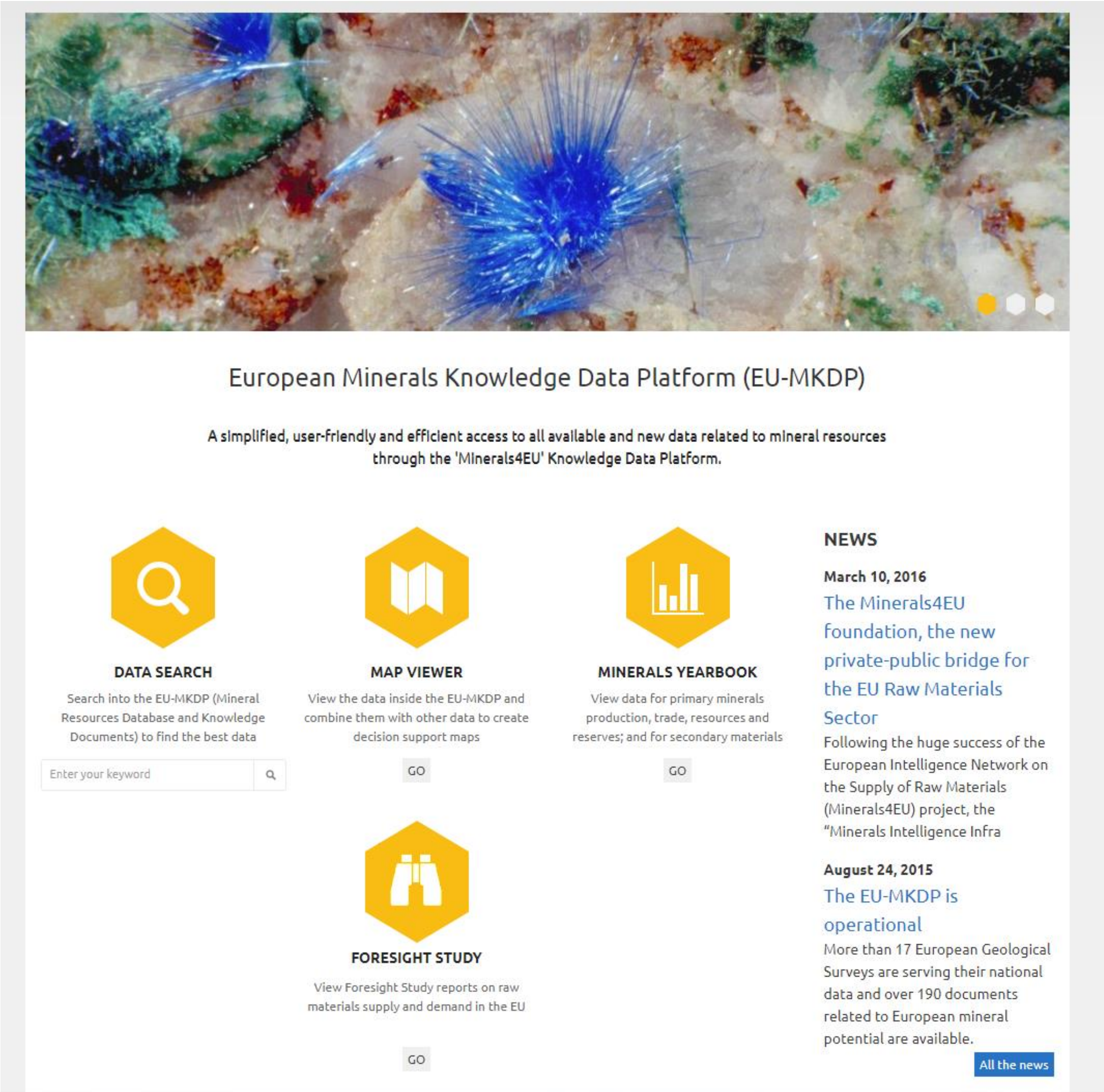

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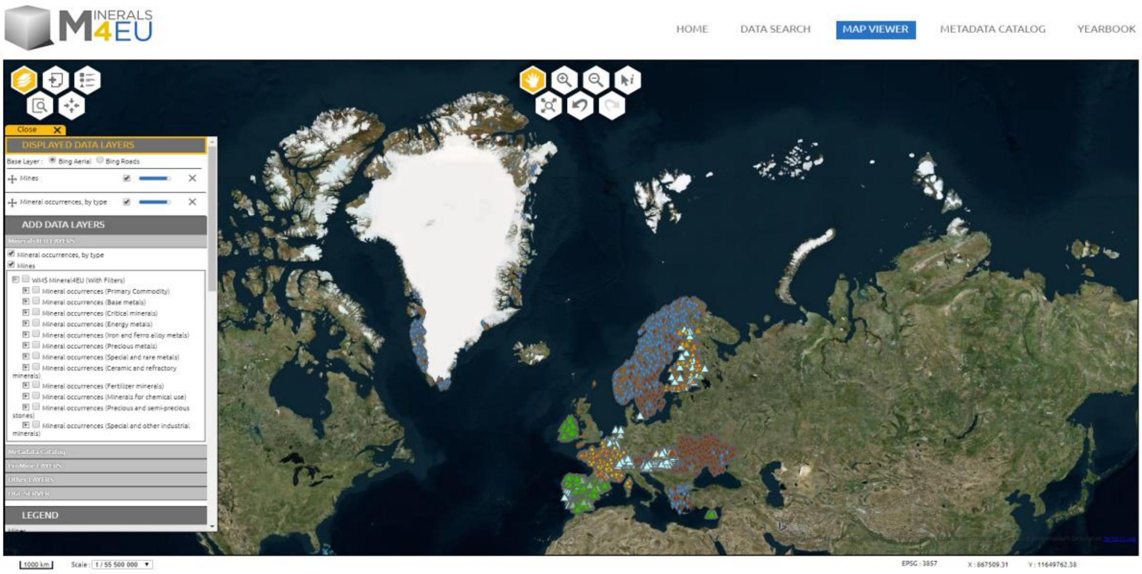

Fig.9: The European Minerals Knowledge Data Platform (EU-MKDP) is now operational. More than 17 European Geological Surveys are serving their national data on mineral resources. Some others will contribute shortly. Over 190 documents related to European mineral potential are stored in the Knowledge base and are available for download.

A task of the EURARE project was to develop an "Integrated Knowledge Management System" (IKMS; Fig. 10; http://eurare.brgm-rec.fr/mapviewer/index.html) that will give access to all available data related to mineral resources containing rare earth elements. It is developed as a data management system, based on high-level interoperability standards, which has integrated advances made in several former EU-FP7 projects such as One Geology-Europe, ProMine and EuroGeoSource, Minerals4EU in terms of database structure, harvesting systems, web services, metadata management, and integration of non-structured information, and InGeoCloudS project in terms of cloud computing. Through this system EURARE contributes to implement the standards of a European geoscientific data infrastructure defined in the EU-FP7 EGDI-Scope project. This IKMS can be accessed through the portal at http://eurare.brgm-rec.fr/. Thus, the role of the IKMS is to provide end-users with a seamless access to the whole value chain from REE deposit exploration, mining and extraction of ore, beneficiation and extraction technologies to treatment of end-of-life products and the generation of "new" materials, with the ability to combine all spatial and non-spatial pertinent information in a single reference system.

The EURARE project includes the whole chain, from rare earth element resources and their classification and distribution, via mining and beneficiation, extraction and separation, to regulation and regulatory frameworks in relation to the REEs. At the most fundamental level are the REE resources the most basic component of an intra-European supply chain. These have been outlined through mapping, characterization and technological and economic evaluation.

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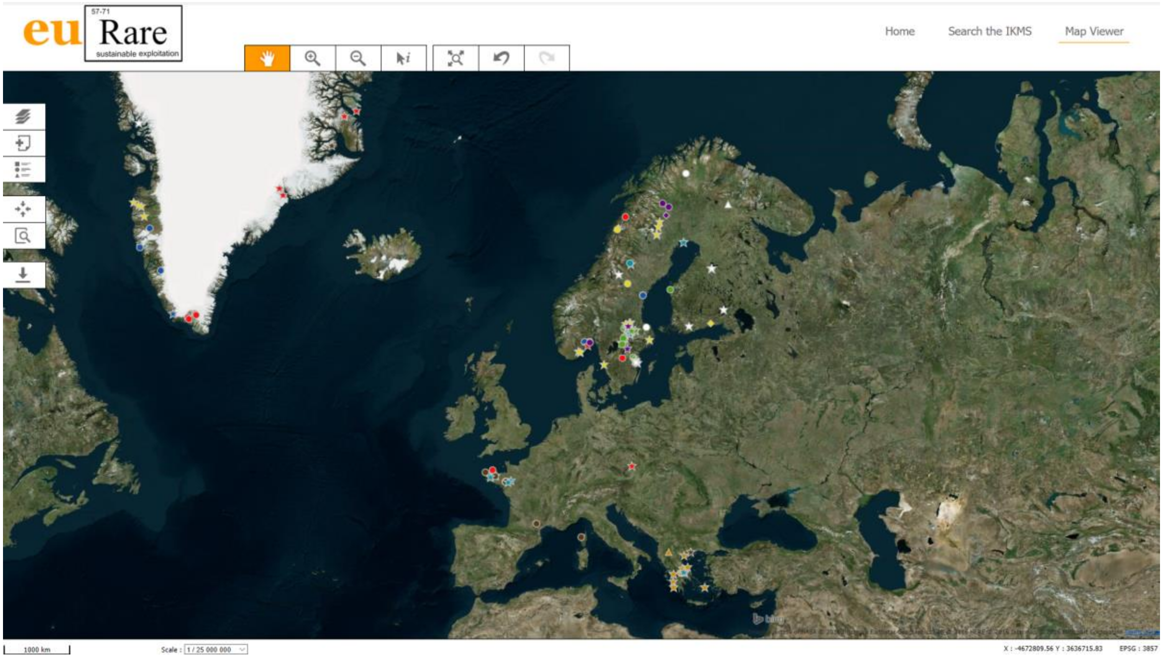

Fig.10: IKMS gives access to all available data related to mineral resources in Europe containing rare earth elements.

The focus of resource studies within EURARE has been on primary, geological occurrences, a task that has been performed primarily by the national geological surveys involved (Britain, Denmark-Greenland, Finland, France, Greece, Norway and Sweden). Thus, direct information about secondary resources was not part of the EURARE project, but the collection and database management (the IKMS; see above) of information on primary deposits which contain quite many occurrences, deposits and mineralisations that have been mined over time, and hence also important information regarding potential sites with secondary (mining waste) resources.

EGDI (http://www.europe-geology.eu/)

EGDI is EuroGeoSurveys' European Geological Data Infrastructure. It provides access to Pan-European and national geological datasets and services from the Geological Survey Organizations of Europe.

EGDI features:

- Central database systems for storing pan-European geological datasets
- Mechanisms for populating these databases with data from National Geological Survey Organisations (NGSOs)
- A metadata base containing a large amount of information about pan-European, national and cross border geological datasets

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- A website including a GIS enabling the user to find and show data related to several topics, search for all datasets available, combine data from different topics, show metadata, etc.

EGDI gives access to datasets and services from a number of pan-European data harmonisation and infrastructure projects, either entirely funded by EGS members or co-funded by the EU, including OneGeology-Europe (geological mapping), EuroGeoSource (energy and minerals), ProMine (minerals), PanGeo (Earth Observation and geohazards), TerraFirma (Earth Observation and geohazards), GeoMind (geophysics), GEMAS (soils and geochemistry) and EMODNet (seabed mapping). For this first version of EGDI a new digital geological map of Europe, developed according to the EC INSPIRE Directive specifications, has been prepared to replace the previous OneGeology-Europe map.

CRM and other strategic minerals can be viewed as:

- Presented in the ProMine database, some CRMs are listed as associated mineralisations and possibly have potential to be extracted from mining waste in case the mine is or was in operation.

- Under category ''Anthropogenic concentrations'' from ProMine database the strategic minerals that can be viewed are: Precious Metals (gold, silver, platinoids), Iron and ferro-alloy metals (iron, chrome, manganese, vanadium, wolfram, molybdenum, nickel, cobalt, niobium), Specialty and rare metals (lithium, beryllium, tantalum, rare earth elements, cesium, rubidium, scandium, zirconium and hafnium, germanium, gallium, indium, cadmium, selenium and rhenium, bismuth, tellurium and mercury, antimony, titanium), Energy commodities (uranium and thorium, coal, lignite and peat, bituminous rocks, petroleum and gas, geothermal energy), and critical mineral raw materials as a separate category.

- Some of the CRM are plotted on the ProMine map viewer with information about the waste and storage types, e.g for Be, Co, Sc, Ga, Ge, W, In and REE, etc. So far this is the second-best place online with secondary CRMs after a primary ProMine website.

- CRMS are part of the Minerals4EU data platform, but only primary CRMs can be viewed e.g. prospects, commodities, deposits etc. (Fig. 11).

<u>Minventory</u> (http://www.minventory.eu/; https://ec.europa.eu/jrc/en/scientific-tool/minventory; https://ec.europa.eu/assets/jrc/minventory/mining-waste-liste.html)

The study on structured statistical information on quality and quantity of EU raw material deposits (Minventory) takes stock of information on mineral reserves and resources that is available in the EU and certain neighboring countries. It supports the creation of a common data base for an efficient resource strategy for the EU's access to raw materials, and it will be one of the building blocks of the European Union Raw Materials Knowledge Base (EURMKB).

Main objectives of the Minventory are to,

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- investigate how to achieve structured statistical information;
- give recommendations and create a roadmap regarding interoperability and harmonisation of data for the European Minerals Yearbook (to be achieved by 2020 and beyond);
- display the findings on an interactive web site.

The study will feed into the EU Raw Materials Knowledge Base, which is one of the objectives of the European Innovation Partnership on Raw Materials described in detail in its Strategic Implementation Plan of 18 September 2013.

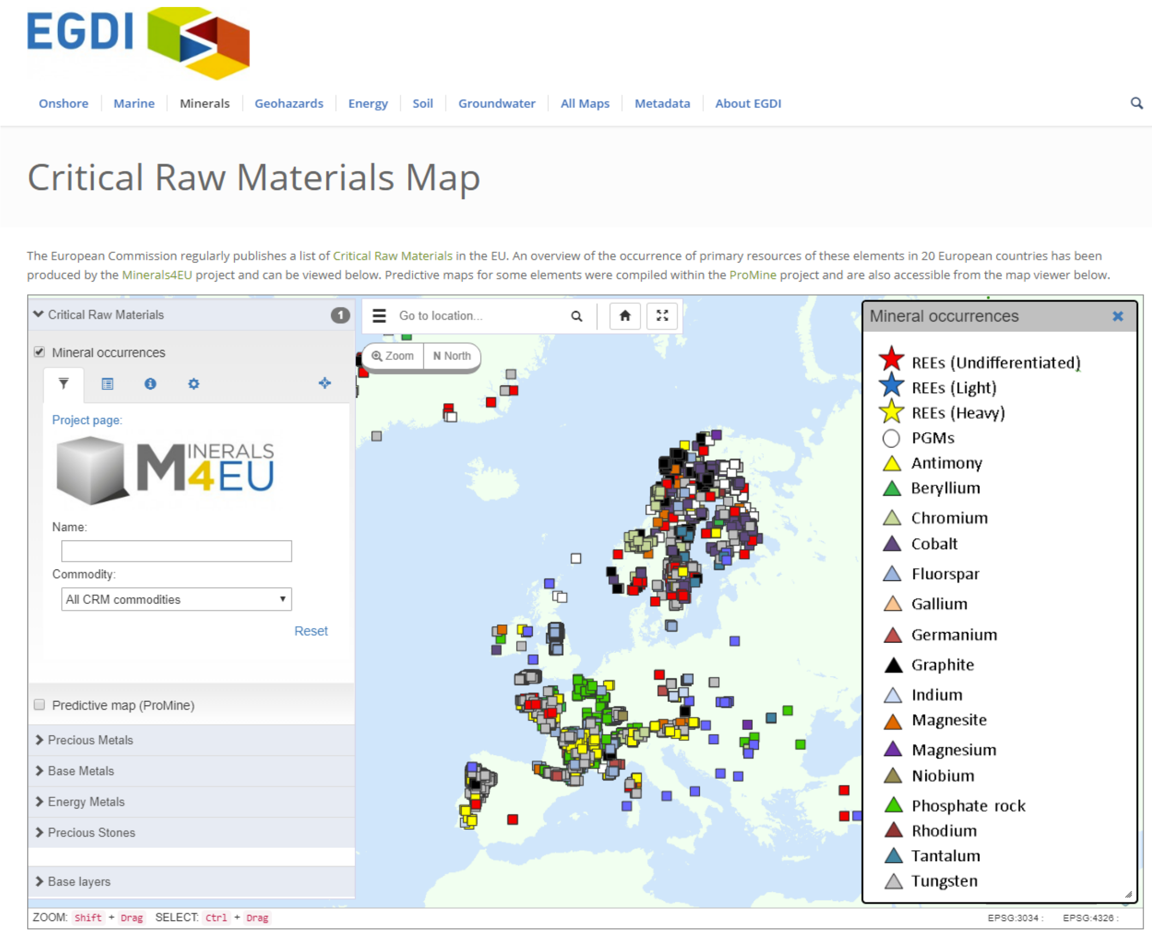

Fig. 11: An overview of the occurrence of primary resources of CRM-related minerals and elements in 20 European countries has been produced by the [Minerals4EU](#) project.

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PROSUM (http://www.prosumproject.eu; http://www.prosumportal.eu/; http://prosum.brgm-rec.fr/mapviewer/)

The ProSUM project is establishing a European network of expertise on secondary sources of critical raw materials (CRM) and other strategic minerals, vital to today's high-tech society. ProSUM directly supports the European Innovation Partnership (EIP) on Raw Materials and its Strategic Implementation Plan calling for the creation of a European raw materials knowledge base. The aim of the ProSUM project was to provide a state of the art knowledge base, using best available data in a harmonised and updateable format, which allows the recycling industry and policymakers to make more informed investment and policy decisions to increase the supply and recycling of secondary raw materials. The ProSUM project has created an inventory for waste streams with a high potential to serve as a source of secondary raw materials.

Data on primary and secondary raw materials are available in Europe but scattered amongst a variety of institutions including government agencies, universities, non-governmental organisations and industry. By establishing an EU Information Network (EUIN), the project coordinates efforts to collect secondary CRM data and collate maps of stocks and flows for materials and products of the "urban mine". Relevant sources for secondary CRMs are electrical and electronic equipment, vehicles, batteries and mining tailings. The project is constructing a comprehensive inventory identifying, quantifying and mapping CRM stocks and flows at national and regional levels across Europe. The availability of primary and secondary raw materials data, easily accessible in one platform, will provide the foundation for improving Europe's position on raw material supply, with the ability to accommodate more wastes and resources in future. Standardised classification methods are needed to bring together dispersed information on mining wastes from several countries into a common database and to compare the metal and mineral potential of mining wastes with the urban mine. Via a user-friendly, open-access Urban Mine Platform (UMP, http://www.urbanmineplatform.eu/homepage), the results are communicated online combining them at the same time with primary raw materials data via the existing EU Minerals Knowledge Data Platform (generated by Minerals4EU). To maintain and expand the UMP in the future, the ProSUM provides update protocols, standards and recommendations for additional statistics and improved reporting on CRM in waste flows required.

Part of the PROSUM project was to collect data on amount and composition of stocks of mining waste (called also mineral-based wastes) and to create a dataset from which deposits with high levels of CRM could be identified. In the ProSUM project, mining waste is divided into two groups: the mining waste generated at the mine during the mining activity, commonly described as waste rock, and the waste generated by the processing of ore at a concentrator, dressing plant or similar in the form of tailings or sludge. Location- wise the waste rock is reported together with the mine whose location is given in Minerals4EU database. These data, which also contain other information about the mining waste such as location, type of waste and origin, will be stored in an extension of the database for primary raw materials, the Minerals4EU database. This database,

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accessible via http://minerals4eu.brgm-rec.fr, makes up an important part of the European Minerals Knowledge Data Platform (MKDP).

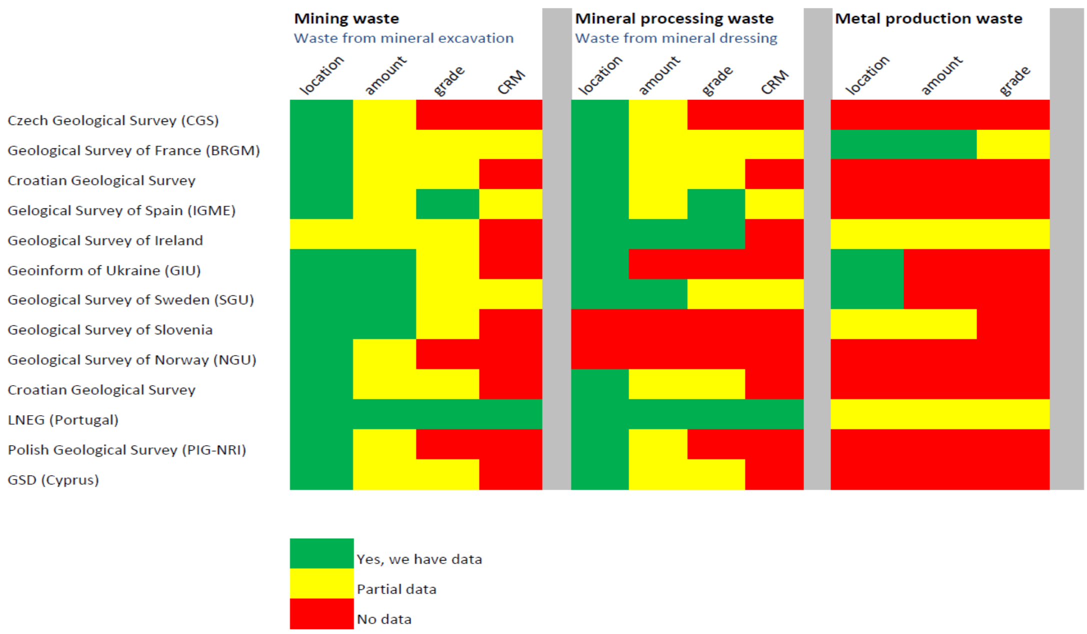
In mining countries, the mining wastes constitute the largest part of society's total waste flow and make up the largest waste stocks but also in countries with historic mining, the mining waste stocks can be significant. The metal grade of mining wastes is low in comparison with some products in the urban mine.

The status of knowledge on mining waste with special reference to critical raw material in each of the participating countries (mostly geological surveys) is summarized in the table below (Table 6). It is obvious that few countries (green) have any quality and quantity data on the three waste types defined.

Every mining, quarrying and mineral processing operation generates mining waste. Figure 12 shows the location of more than 1600 mines for which the amounts of waste rock have been roughly calculated.

Mining waste does not follow the same legislation as other product groups in ProSUM. There is no EU legislation that requires recycling of mining waste, there is no major recycling industry, there are sparse Eurostat statistics on mining waste and only at a country level

Table 6. Current state of resource and compositional data on CRM in mining, mineral processing and production wastes among some EU member states (Source: ProSUM).



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The PROSUM project has gathered data and conducted sampling and analysis of mining waste to present complete characterizations of this waste group, including CRMs. The focus in the data gathering have been locations of mines (already available in Minerals4EU) and mineral processing plants, types of processes that produced the waste, types of wastes and amount and composition of the waste. This data is stored in a ProSUM extension to the Minerals4EU database.

One of the main goals in ProSUM for mining wastes was to create a common framework for the collection and storage of data on mining waste including location, amount and composition. The target was to gather data on the most important waste deposits with respect to the critical raw materials (CRM) as well as the common commodities. Collection of data on mining waste from the participating countries was based on the data model and code lists for mining wastes completed in ProSUM. The selection was determined, in order of priority, by:

- Size of waste deposit
- Metal and/or mineral content
- Critical raw materials content
- Active mines and processing plants
- Small mining waste deposits

The reason why CRM were not given a top priority is that most of the data available are limited to those commodities (e.g. iron and alloy metals, base and precious metals) that gave economic viability to the mine or processing plant. Rare metals and minerals with lower economic or environmental importance, including several of the CRM, were seldom analyzed and reported.

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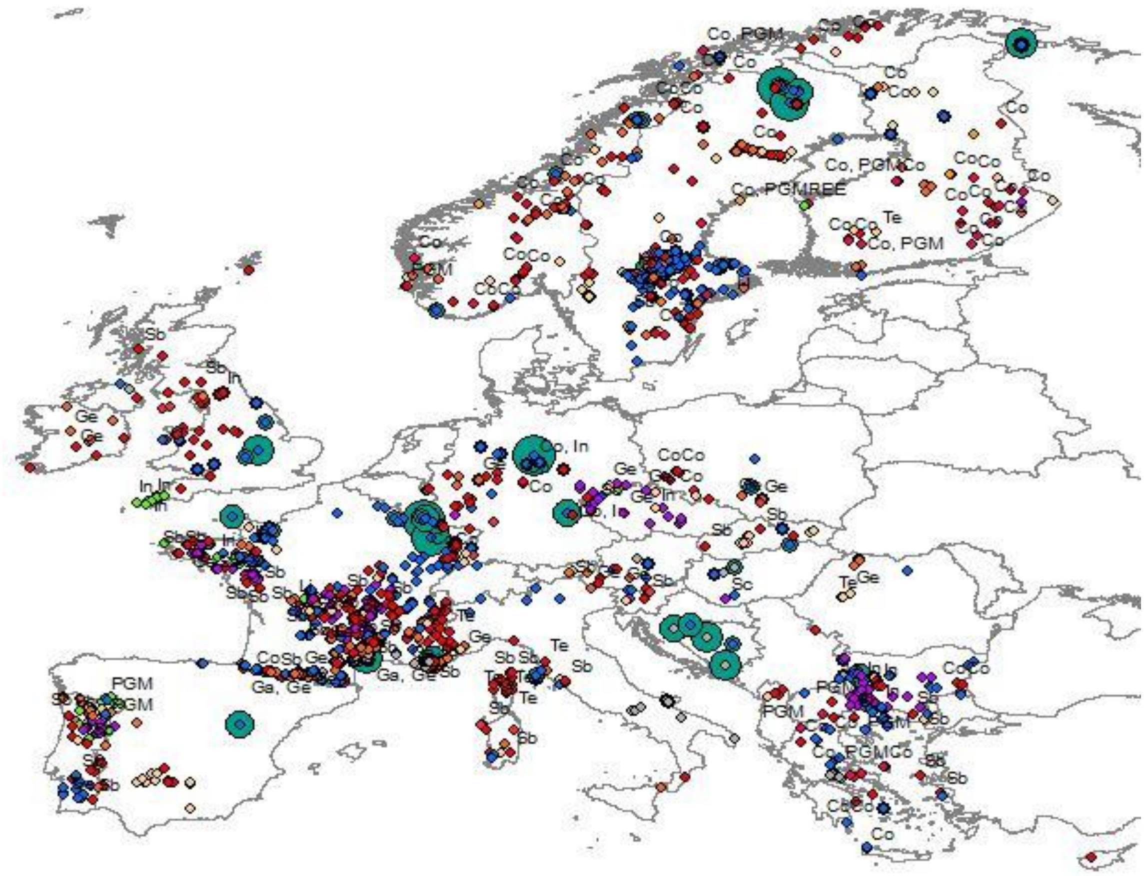

Figure 12. Map of Europe showing closed and operating mines. The green circles represent the calculated amount of waste rock where the largest circles represent more than 500 Mt of waste rock. Diamonds represents smaller mines and the colors represents type of ore; blue for iron and iron-alloy metals, yellow for precious metals, red for base metals, grey for bauxite, violet for energy metals (U) and green for special metals. Data from:

ProMine- http://promine.gtk.fi/ and,

FODD (http://en.gtk.fi/informationservices/databases/fodd/).

The bulk of the available data on ore, mineral processing and mining waste come nowadays from the extractive industry and can be found in annual reports or environmental reports. Their data are based on several thousand of analyses taken during the operations and it is assumed that these data are correct and representative. For other data sources, i.e. environmental investigations made by government authorities, research reports etc. the analytical methods are, in most cases, reported and can be used to evaluate the analytical quality.

Mining waste, as also notified above, has mostly been regarded as an environmental problem; it is only in recent years that the economic potential has been recognized. The previous lack of

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economic interest means that there are limited data on the amounts of mining waste (waste rock, tailings, waste sludge etc.) produced and accumulated in stocks (waste rock landfills, tailing and sludge dams).

Mining of metallic ores is an extractive industry which results in waste rocks which, due to its low economic value, in most cases are deposited close to the mine. Some of the rock is used as backfill in mines, for dam construction or for other infrastructure purpose, at the mine site or near the mine. The remaining waste rock is deposited in a waste rock deposit.

The proportion of the ore to the concentrator that becomes waste is highly dependent on type of ore. For example, for gold ores and low-grade base metals ore almost all the processed ore becomes waste while around 30% of the iron ore becomes waste. Table 7 shows some well documented cases where the proportion of ore that become waste is given.

Table 7. Preliminary approach showing the portion of the ore that becomes waste during mineral processing of different types of ore in Sweden (Source: ProSUM).

Type of deposit	Waste (%)	Examples (Sweden)
Low grade ore (porphyry copper, gold ore)	99	Aitik, Björkdal, Åkerberg
Disseminated ore (Skarn deposits, sandstone hosted)	94	Laisvall, Yxsjöberg
Massive sulphides	75	Kristineberg, Boliden, Zinkgruvan
Iron ore	30	Kiruna, Grängesberg

Several of the critical raw materials have never been extracted on a large scale in the EU and therefore the amount of available analytical data is limited, especially compared to the data on primary resources.

Alternative sources to mining waste data include environmental reports and mine site remediation reports conducted by environmental authorities and mining companies, data from work by national surveys in accordance with the Mining Waste Directive and scientific reports dealing with various aspects of mining waste. However, as mentioned above, the research made on the national inventories of mining wastes related to the implementation of the MWD showed that any compositional information provided is very limited and of uncertain quality.

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MICA (http://www.mica-project.eu/)

MICA (Mineral Intelligence Capacity Analysis) project does not generate new data but reviews existing datasets and develops metadata records related to raw material intelligence. The MICA plans to create an online data inventory e.g. from other project libraries e.g. Minerals4EU, EURARE.

Data gathering has initiated and there are currently approximately 180 metadata records produced which comprise the draft data inventory. The metadata template and subsequent records are linked to the MICA Online Platform. An online data portal is currently under development, which will allow access to all the metadata records being produced.

A total of 408 records now form part of the MICA metadata inventory. Out of the 408 records identified, 370 metadata records have been fully prepared and the remaining 38 are in the pipeline and will be delivered shortly. Online metadata inventory is under construction. A beta-version of the online metadata MICA inventory has become publicly available, which contains a first batch of 101 records. The content of the MICA metadata inventory varies considerably. It includes datasets, but also scientific articles, reports, websites (e.g. for trade associations), maps, project information, information about relevant legal documents etc.

(http://metadata.bgs.ac.uk/mica/srv/eng/catalog.search#/home).

SCRREEN (http://scrreen.eu/)

Many databases have also been developed to help gather this information, but they have sometimes duplicated existing work. Past, ongoing and recent networks and projects such as ERECON, CRM_InnoNet, MSP-REFRAM, but also Minerals4eu, MICA, MIN-GUIDE, PROSUM, Smart Ground, INTRAW, cycLED, etc., have produced several in-depth studies that have created a good level of baseline information on several CRMs. A few R&D&I actions also address some specific steps of the value chains of CRMs (FAME, Optim'ore, IntMet, CloseWeee, REE4EU, Infinity, INREP).

In addition, several associations have contributed to structuring the community, covering nearly all of the fields related to raw materials and including CRMs in particular. The European Commission itself has initiated several activities including the further development of the Raw Materials Information System to facilitate its needs with regards to the European Union Knowledge Base on Raw Materials with links to the European Innovation Partnership on Raw Materials and to the European Innovation and Technologies Knowledge Innovation Communities (EIT – KICs), amongst others.

SCRREEN is addressing and contributing in improving Europe's strategy by,

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- Identifying primary and secondary resources as well as substitutes of CRMs and their respective qualities, which are available to Europe (mapping, assessing, quantifying) in an international context
- Estimating the expected EU demand for various CRMs in the future and identifying major trends
- Providing policy and technology recommendations and actions to produce various primary and secondary CRMs and for their potential substitution, to secure their supply and decrease the relative dependence on imports
- Providing a plan for transparent consultation with relevant external stakeholders and effective communication of the findings to the professional and public across the EU
- Allowing for possible changes in the CRM list by offering quick flexibility through value chain approaches and efficient solutions for the integration of relevant stakeholders in the SCRREEN network.

The objectives of SCRREEN aim at,

- Establishing an EU Expert Network that covers the whole value chain for present and future critical raw materials. It will build on existing structures and initiatives, as well as international collaborations, and will aim at clustering related EU projects and initiatives. This network will be set up as a permanent forum for policy-makers, industry and society who are interested or are involved in raw materials. It will encourage permanent dialogue between stakeholders and support strategy and policy development, and decision-making.
- SCRREEN looking into approaches that ensure the viability and sustainability of the network after the project ends to make it a long-lasting structure.
- Analysing pathways and barriers for innovation and identify the solutions for overcoming these barriers. These should enable technology breakthroughs, substitution options, new resources (primary, secondary, urban mines) etc.
- Studying the regulatory, policy and economic framework for the development of these technologies; identify related gaps/barriers and limitations; and propose ways to move forward, while looking at end of life issues, especially for waste electrical and electronic equipment or waste batteries. The objective is to lift barriers and ultimately boost the creation of new markets in Europe, inducing job and wealth creation.
- Identify the knowledge gained over the last years and ease the access to these data widely and efficiently, beyond the project. SCRREEN will collect and organise all the data generated in other projects, associations, initiatives etc., and develop a knowledge data portal.

Through the EU CRM Knowledge Base (http://scrreen.brgm-rec.fr/) it will be possible to,

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- Search to find the best information
- View the Critical Raw Materials deposits in Europe and combine them with other data to create decision-support maps (Fig. 13).
- View applications of the Critical Raw Materials Knowledge Base

EMODnet (http://www.emodnet.eu/)

The European Marine Observation and Data Network (EMODnet) consists of more than 150 organisations assembling marine data, products and metadata to make these fragmented resources more available to public and private users relying on quality-assured, standardised and harmonised marine data which are interoperable and free of restrictions on use. EMODnet is currently in its third development phase with the target to be fully deployed by 2020. Identifying and mapping areas of minerals (including aggregates, oil and gais and metalliferous minerals), and arranging web-mapping services with holders of data on mineral resources is one of the specific objectives of EMODnet geology (Fig. (http://www.emodnet.eu /text-geology).

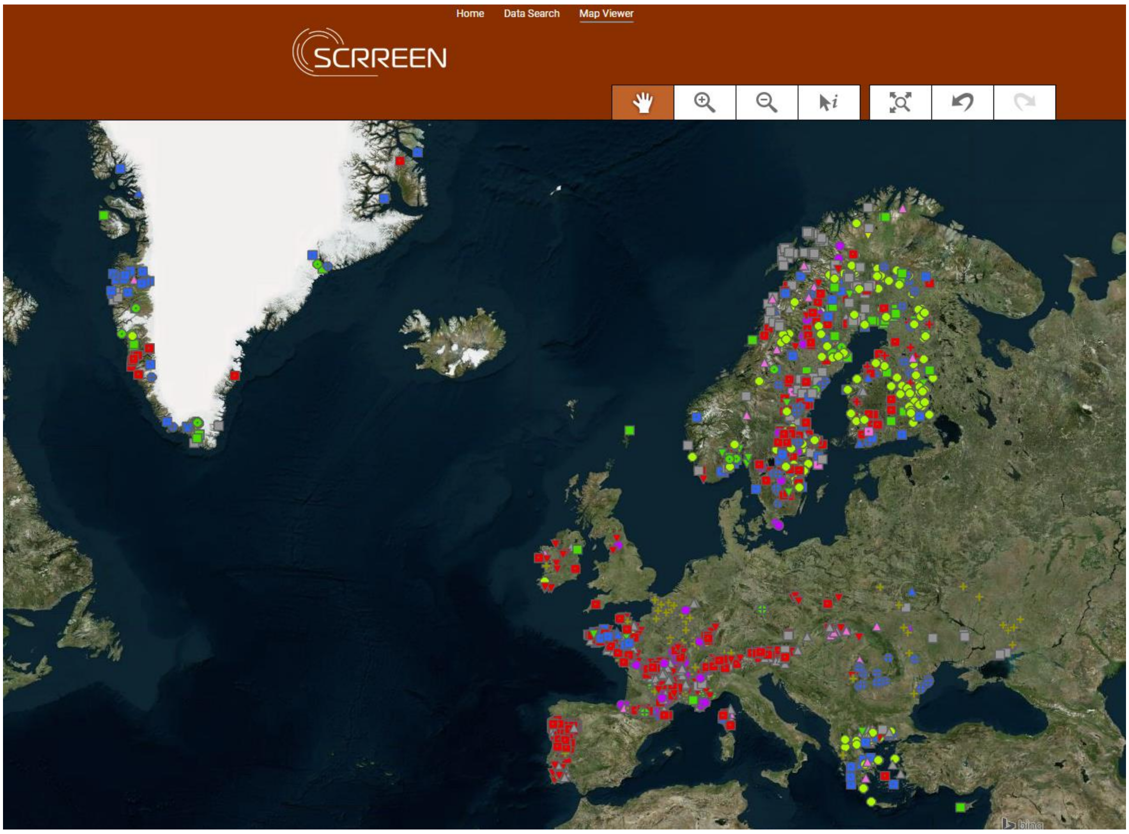

Fig. 13. Map viewer hosted by SCRREEN data portal showing CRM deposits in Europe

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3.2 National Projects

The Mineral Resources Expert Group (MREG) of EuroGeoSurveys has a task team with the functional role to register the project activities carried out by European Geological Surveys at national level. This task team has the mandate to hold a record, give a brief description and monitor the progress of ongoing national projects addressing mineral resources and any other topics and issues of relevance. The data included are all provided by each country's Geological Survey and listed in an excel format. The information delivered is available to the public and is updated annually.

The last update is from April 2017 and includes contributions from 27 countries, namely, Albania, Austria, Belgium, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Federation of Bosnia and Herzegovina, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, United Kingdom. A total number of 472 finalised and ongoing projects was reported (Fig. 14), corresponding to 725 fields of multi-disciplinary activities (Fig. 15) approaching issues and topics related to mineral resources. Impressive number of 1372 commodities (Fig. 16) was addressed, with metallic and industrial minerals, and construction materials dominating. Going back to the 725 thematic fields of project activities, an analysis of the information provided shows that less than 100 deals with mining wastes (Fig. 17), whereas country wise 20 of the 27 reporting countries have CRM related projects (Fig. 18).

It is obvious that majority of the countries have incorporated mining wastes and CRM economic geology and exploration activities into their project planning. This is a finding that's becoming a clear trend among the group of ongoing and recent projects.

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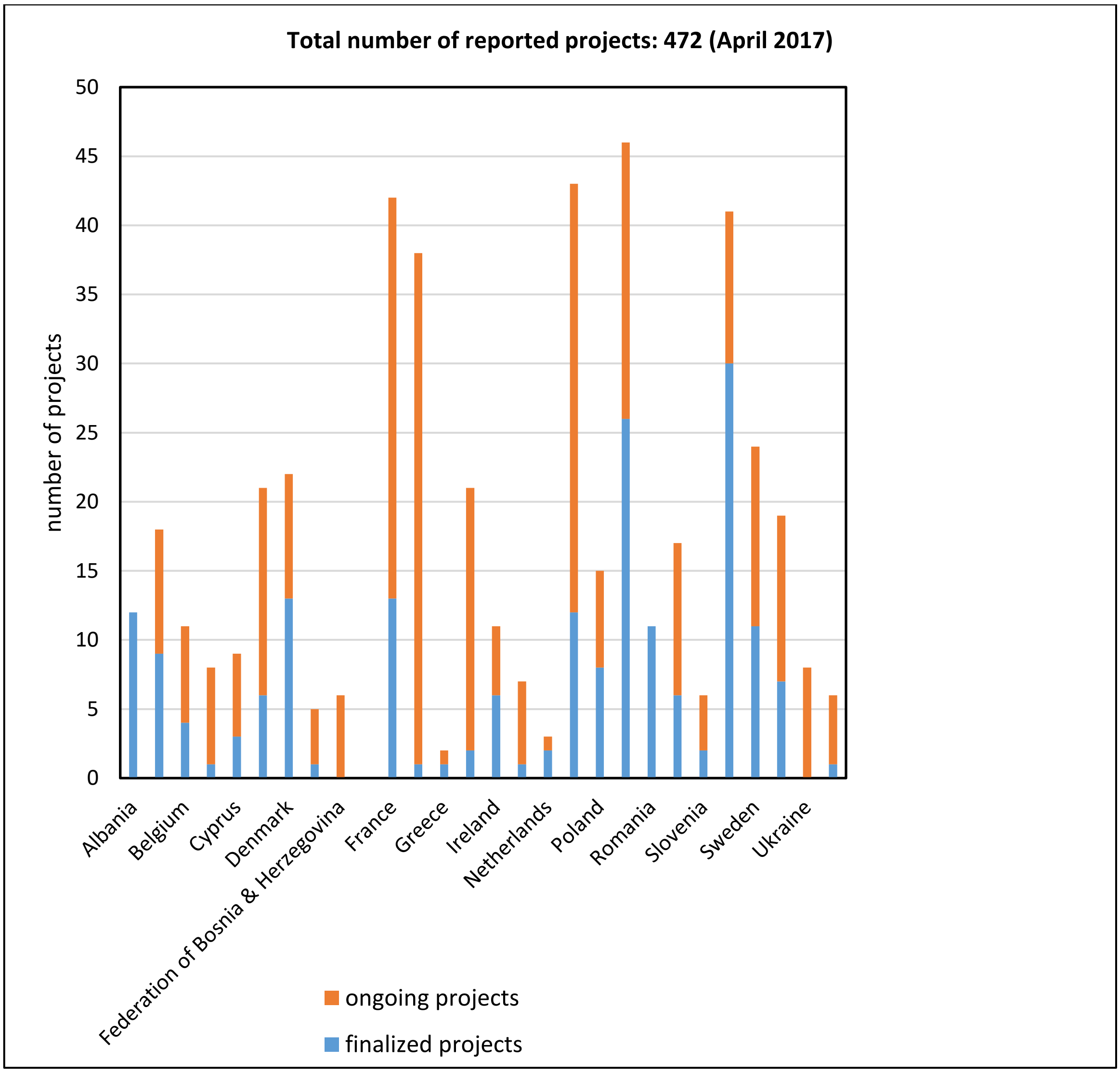

Figure 14. Finalised and on-going national projects carried out by European geological surveys (last update from April 2017).

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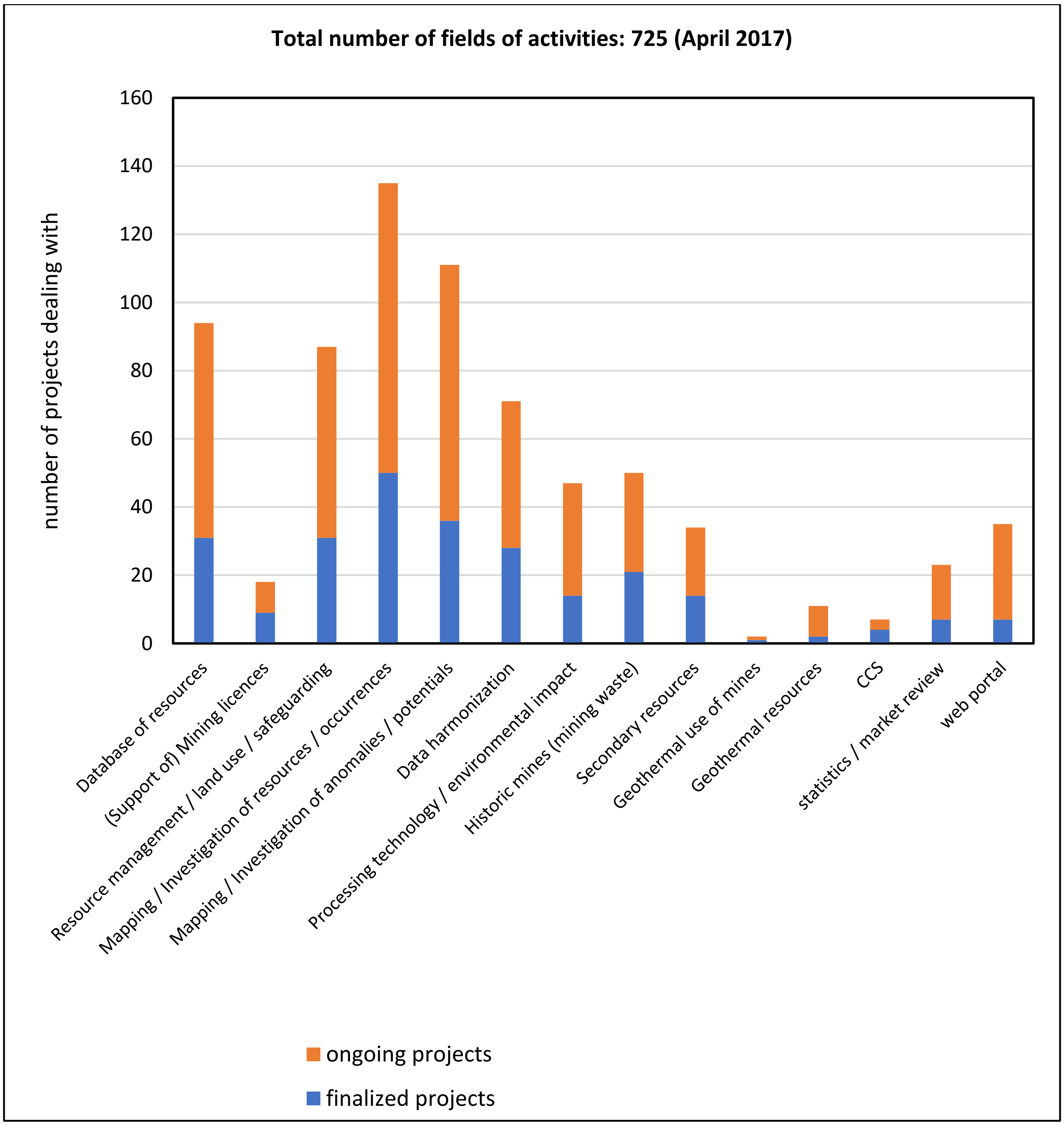

Figure 15. Geo-thematic topics addressed by national projects undertaken by European geological surveys.

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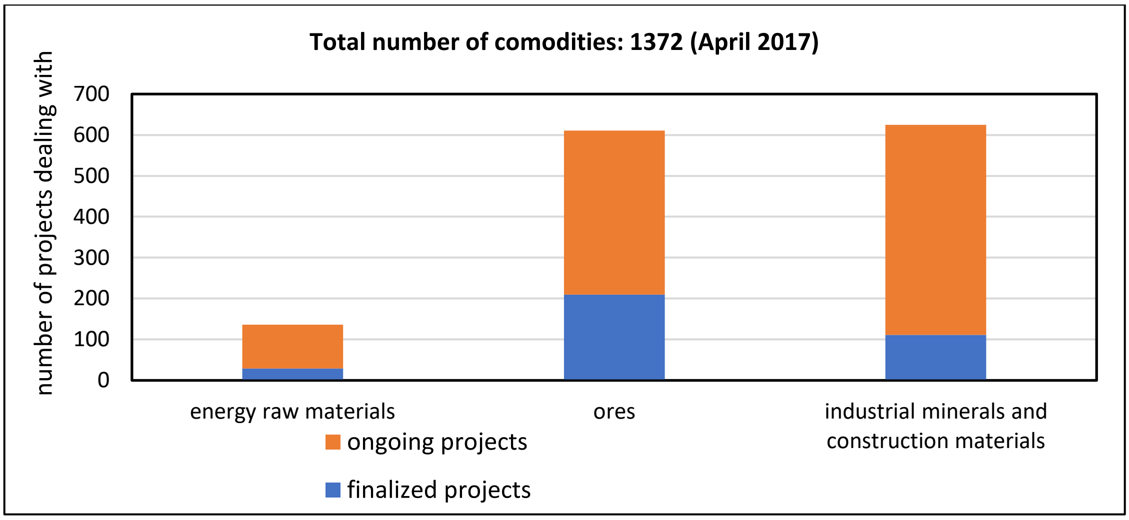

Figure 16. Most of the European geological surveys´ national projects deal equally with metallic and industrial minerals.

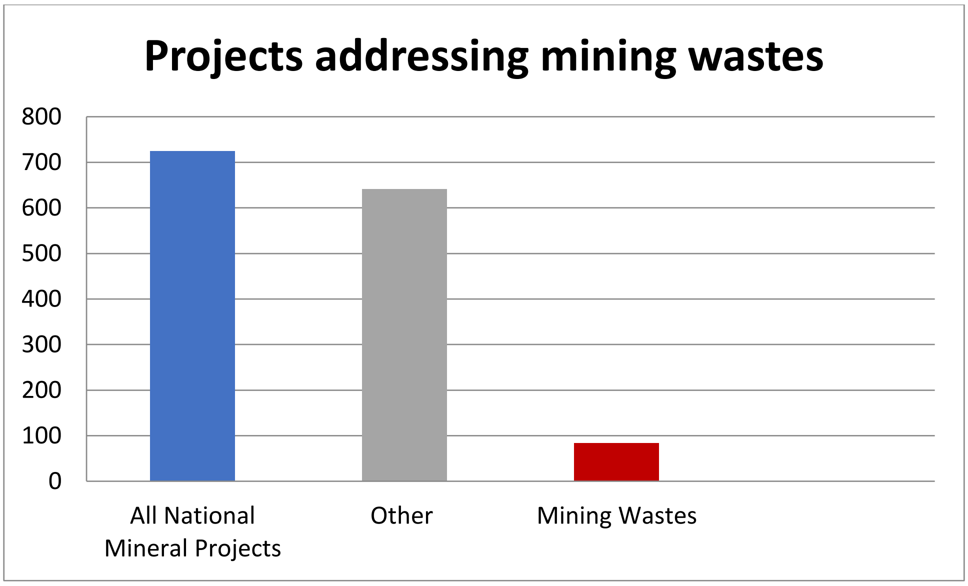

Figure 17. During last years, mining wastes related issues have become major project targets.

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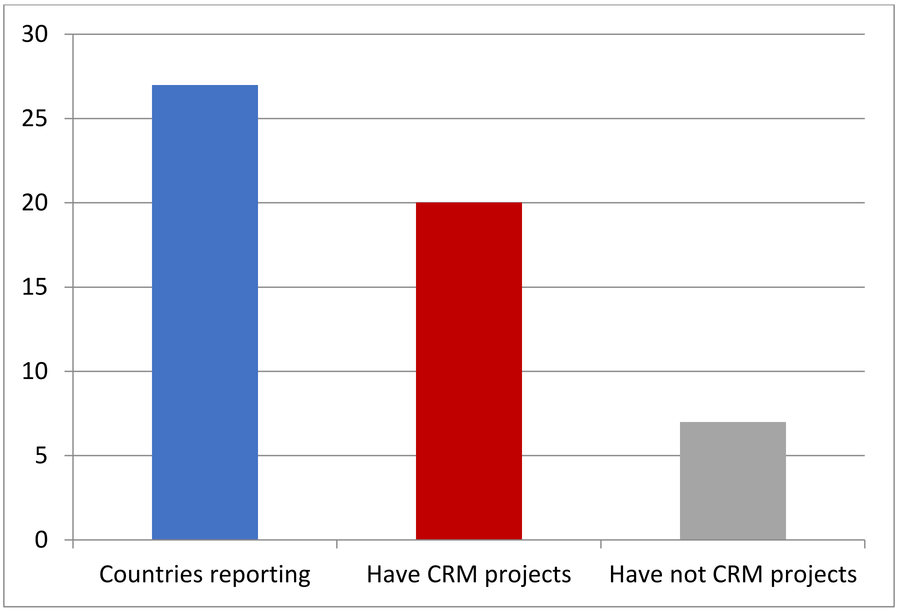

Figure 18. The CRM are central in national projects of most European countries.

3.3 Established mineral data platforms

EUROSTAT provides aggregated annual mineral statictics on country basis.

http://ec.europa.eu/eurostat/statistics-explained/index.php/Mining_and_quarrying_statistics_-_NACE_Rev._2

http://ec.europa.eu/eurostat/web/waste

The JRC Raw Materials Information System (RMIS)

http://rmis.jrc.ec.europa.eu/;https://ec.europa.eu/growth/tools-databases/eip-raw-materials/en/content/jrc-raw-materials-information-system)

The RMIS is a comprehensive online repository of information on policies, activities and data related to the European raw materials sector. It supports a series of European Commission initiatives which aim to tackle the pressure on valuable resources and their more efficient use to the benefit of EU's economies. It provides a structured repository of knowledge on non-energy-related raw materials. This includes links to data, methods, approaches and indicators related to the most relevant activities on raw materials in a European context and beyond. The RMIS thereby contributes to consolidating the EU raw materials knowledge base and aims at strengthening the visibility and competitiveness of the EU raw materials sector, while promoting green and sustainable growth (Fig. 19).

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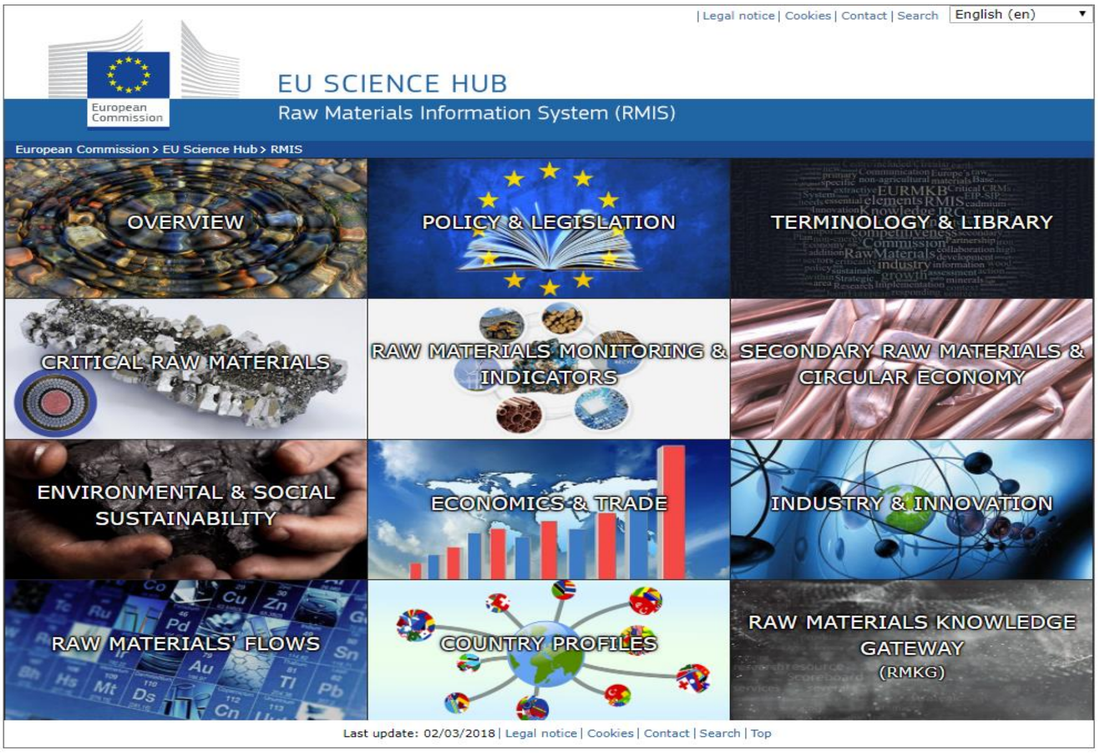

Fig. 19 : RMIS is a comprehensive online repository of information on policies, activities and data related to the European raw materials sector.

<u>British Geological Survey (BGS) Mineral Statistics</u>

(http://www.bgs.ac.uk/mineralsUK/statistics/worldStatistics.html)

<u>BGS provides</u> provide information on world mineral production and related commodities (Fig. 20).

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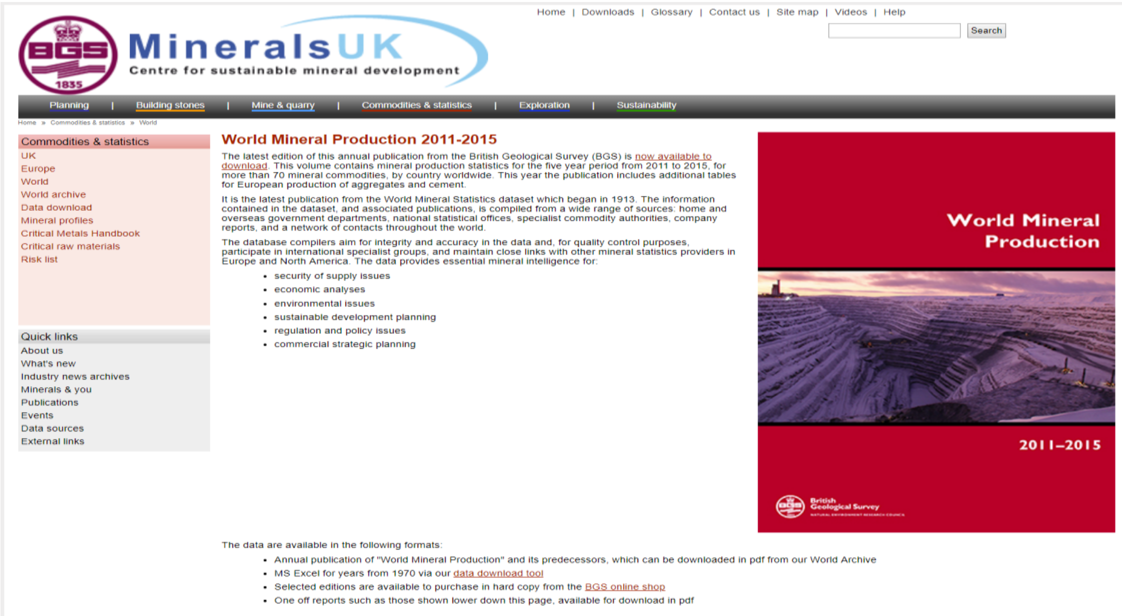

Fig. 20: Web portal of the British Geological Survey (BGS) where mineral statistics are presented.

<u>USGS Mineral Statistics</u> (https://minerals.usgs.gov/minerals/pubs/commodity/) providing worldwide information on mineral resources along with resource and production figures (Fig. 21).

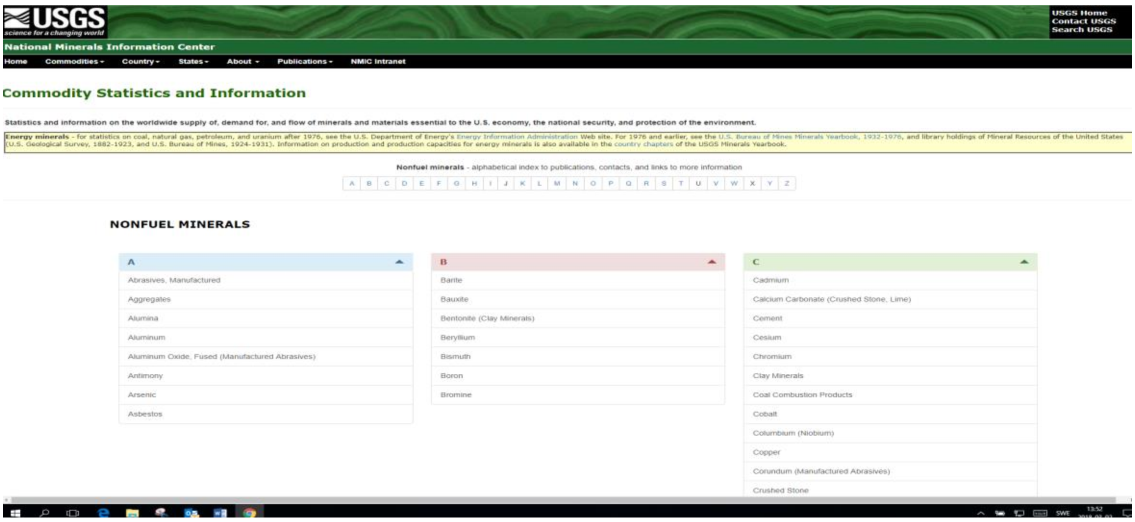

Fig. 21: Web portal of the United States Geological Survey (USGS) where mineral statistics are presented.

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<u>Fennoscandian Ore Deposits database (FODD) and Maps</u>

(http://en.gtk.fi/informationservices/databases/fodd/index.html)

The Fennoscandian Ore Deposit Database (FODD) is a comprehensive numeric database on metallic mines, deposits and significant occurrences in Fennoscandia (Fig. 22). The maps and the database have been compiled in a joint project between the geological surveys of Finland, Norway, Russia and Sweden. The database contains information on nearly 1700 mines, deposits and significant occurrences across the region. The FODD contains information on location, mining history, tonnage and commodity grades with a comment on data quality, geological setting, age, ore mineralogy, style of mineralisation, genetic models, and the primary sources of data. The list of critical metals and minerals is mostly based on European Commission's Raw Materials Initiative of 2008, updated in 2014 and 2017 in which 26 economically important metals and minerals, that are subject to a higher risk of supply interruption are labeled as critical (e.g. REE, PGE, Co, W, Be, fluorspar, graphite etc.).

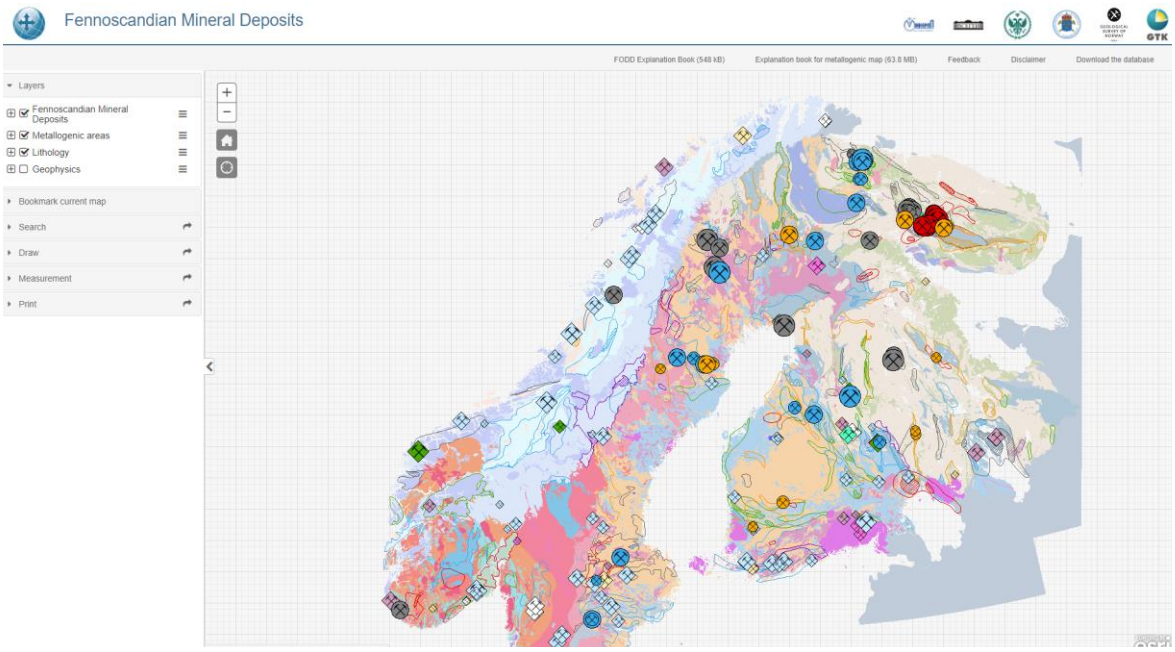

Fig. 22: The FODD provides detailed information on the mineral deposits and their relationship to lithology and geophysical information.

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3.4 Data received from other GeoERA raw materials projects and FRAME WPs

Mintell4EU- Mineral Intelligence for Europe

Data collection and related information of strategic minerals carried out during the FRAME project and WP3 will address and implement the harvesting methodology, instructions and guidelines by the GeoERA raw materials MINTELL project in order to improve the overall EURMKB and more specifically to deliver:

• Updating of the European Minerals Yearbook with production and trade data (2014-2017), and resource and reserve data as well as exploration information (reference year 2019);

• Integration of the European Minerals Yearbook in the INSPIRE-compliant Minerals4EU database;

• Improving the quality and spatial coverage of the Minerals Inventory, addressing harmonization issues and facilitating interoperability with other ongoing European mineral intelligence project;

• Testing the application of the UNFC classification system as a tool to obtain more accurate pan-European mineral inventories;

• Recommendations of communication and interaction between already existing databases and data portals, and the Raw Materials Information System (RMIS);

• Integration of the European Minerals Yearbook and Minerals Inventory in the GeoERA Information Platform and provide user-oriented search and visualisation facilities, thereby de-facto establishing a dedicated EURMKB portal, but also enabling interoperability of raw materials data with data on groundwater and geo-energy resources to support spatial planning and management of competing land-uses.

FRAME WPs 4, 5, 6 & 7

There are obvious and clear linkages between WP3, WP4, WP5, WP6 and WP7 of the FRAME project (Fig. 23) when it comes to collecting respective strategic minerals data and information based on common harvesting methodology and being compliant to INSPIRE.

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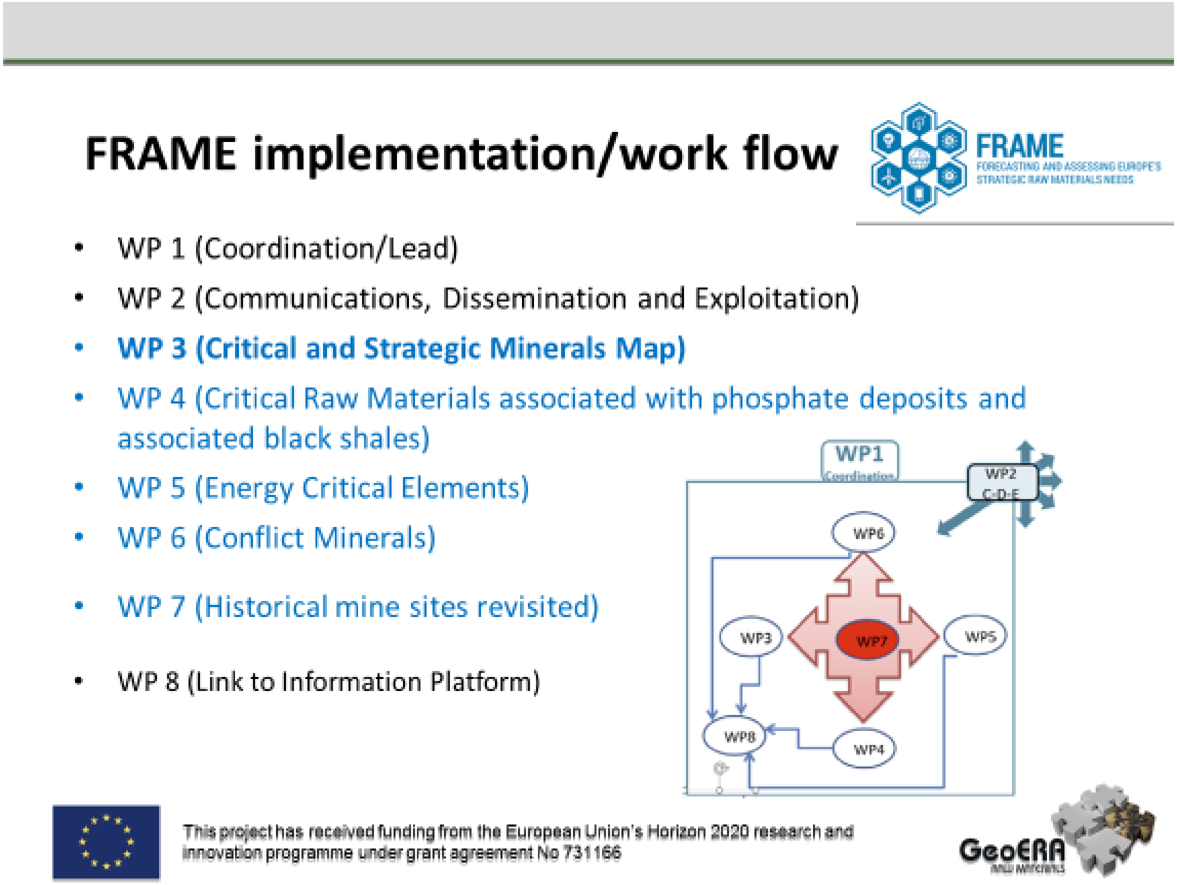

Fig. 23: FRAME WPs that will jointly contribute to the production of the critical and strategic minerals map.

3.5 Data received from RMSG survey on battery minerals

DG GROW's Raw Materials Supply Group (RMSG) has in progress a survey on battery minerals to be nationally coordinated and carried out by members of the SHERPA group. The focus is on four raw materials: cobalt, lithium, nickel and natural graphite for battery in e-vehicles and energy storage. Optionally, information also on additional battery relevant minerals, including aluminium, copper, germanium, magnesium, manganese, rare earths elements, silicon metal and tin, could be provided. The survey is aiming to collect information on exploration, production, and on resources and reserves reflecting the UNFC/CRIRSCO classification systems. Policy and regulatory framework information, also requested, is adapted to give the opportunity to report on both: actions promoting domestic production of battery mineral raw materials within the EU and actions for sourcing from other countries. The information provided will be shared between Member States governments and the European Commission for all involved to benefit from this exercise, approval will be asked prior to sharing it with third parties. Results will be discussed with the combined Sherpa group of the EIP Raw Materials and RMSG on 9 October and presented at

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the 6th High Level Conference of the European Innovation Partnership (EIP) on Raw Materials on 14 November 2018.

3.6 Strategic minerals data collection within FRAME

As mentioned and discussed and listed above, namely in chapter 2 and table 4, the critical and strategic mineral raw materials to be included and targeted in the FRAME project are:

- Those classified as CRM for the EU
    - Antimony (Sb)
    - Gallium (Ga)
    - Magnesium (Mg)
    - Scandium (Sc)
    - Baryte
    - Germanium (Ge)
    - Natural graphite
    - Silicon metal (Si)
    - Beryllium (Be)
    - Hafnium (Hf)
    - Tantalum (Ta)
    - Bismuth (Bi)
    - Helium (He)
    - Niobium (Nb)
    - Tungsten (W)
    - Borate
    - HREEs-Heavy Rare Earth Elements
    - *(Dysprosium-Dy, Erbium-Er, Europium-Eu, Gadolinium-Gd, Holmium-Ho, Lutetium-Lu, Terbium-Tb, Thulium-Tm, Ytterbium-Yb, Yttrium-Y)*
    - LREEs-Light Rare Earth Elements
    - *(Cerium-Ce, Lanthanum-La, Neodymium-Nd, Praseodymium-Pr, Samarium-Sm)*

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  - PGMs-Platinum Group Metals
  - *(Iridium-Ir, Palladium-Pd, Platinum-Pt, Rhodium-Rh, Ruthenium-Ru)*
  - Vanadium (V)
  - Cobalt (Co)
  - Indium (In)
  - Phosphate rock
  - Fluorspar
  - Phosphorus (P)
- Those considered to be strategic for reasons mentioned in chapter 2
  - Tin (Sn)
  - Nickel (Ni)
  - Manganese (Mn)
  - Copper (Cu)
  - Lithium (Li)
  - Selenium (Se)
  - Tellurium (Te)
  - Iron (Fe)
  - Gold (Au)
  - Silver (Ag)
  - Chrome (Cr)
  - Molybdenum (Mo)
  - Rhenium (Re)
  - Titanium (Ti)
  - Osmium (Os)

The data of all strategic minerals raw materials will be collected by respective Work Packages (WPs) the following way,

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- WP3 (Critical and Strategic Minerals Map) will collect data of all minerals except from those of Li, Co, graphite, Nb and Ta
- WP 4 (Critical Raw Materials associated with phosphate deposits and associated black shales) will collect data on P, F, REE, Be, Sb, Co, PGM, V and Cr associated phosphate deposits and black shales
- WP 5 (Energy Critical Elements) will collect mineral data of Li, Co and graphite
- WP 6 (Conflict Minerals) will collect mineral data of Nb and Ta
- WP 7 (Historical mine sites revisited) will collect mineral data from mining wastes

Each partner joining the WPs mentioned above is requested to provide a filtered raw data export from their national mineral deposit database, that is harmonized to the FRAME needs as explained below, considering that at this stage only points, not any areas for the occurrences.

The following data is requested, and is mandatory from each occurrence that is considered a resource for the critical and strategic minerals mentioned above (main substance or substance contained):

1. Id = your national database id to occurrence
2. Name= the occurrence name
3. Latitude and longitude in decimal degrees
4. The element type: Li, graphite or Co
5. Deposit type: occurrence, prospect or deposit**,** as defined by Inspire. To be a deposit a resource and grade estimate is required; Information about geological setting, age, grades and mineralogy to be also provided
6. Deposit type hosting strategic minerals and metals as associated commodities (e.g. Re in porphyry Cu-Mo deposits or Ga in bauxite deposits).
7. Status of the occurrence
    a. Active
    b. Closed
    c. Not exploited

Most national databases have their resources classified so that a raw data extract could be done easy and with a small editing harmonized to the FRAME.

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4. Strategic mineral deposits types

To develop metallogenic research and exploration models at regional and deposit scales the FRAME is aiming to identify and study the geotectonic settings and major deposit types which may host potential resources of strategic minerals. Better understanding of the ore genetic links between major deposit types and hosted strategic mineral associations will make an asset for the sustainability of their supply and related value chains. The respective classification of strategic minerals to specific and certain types of deposits will consider,

- Mineralisations and deposits on land and the marine environment in which strategic minerals and CRM make the main commodities, e.g. REE minerals related to carbonatite, nepheline syenites, pegmatites or paleoplacers, tungsten deposits related to granites, lithium feasible pegmatites, graphite hosted by schists. For example, the EURARE project reported that the rare earth elements (REE) occur in several environments within the Earth's crust. They may be found in igneous, sedimentary, or metamorphic rocks of a wide range of different ages. However, enrichments in the REE can typically be divided into two classes: primary types, generally formed by igneous or hydrothermal processes, and secondary, in which the REE have been further concentrated from a primary enrichment through sedimentary processes or weathering. Primary types are typically veins, layers or zones of REE enrichment within the bedrock; secondary types may include weathered horizons such as laterites, placers, and sea-floor sediments. The most significant primary types of REE enrichment are those associated with alkaline silicate igneous rocks and carbonatites (Fig. 24). REE enrichments can also be found associated with hydrothermal veins, breccias and metasomatic zones in a variety of sedimentary and metamorphic environments. Primary enrichments in the REE may then be upgraded further by secondary processes. Tropical weathering of alkaline silicate igneous rocks and carbonatites may form laterites or ion-adsorption clays. River and beach sedimentary processes may also concentrate those heavy minerals into placer deposits. The REE are found in a wide range of minerals, including silicates, carbonates, oxides and phosphates (Sadeghi et. Al. 2014, 2017; Arvanitidis and Goodenough, 2014; Goodenough et.al. 2016).

- Mineralisations and deposits on land and the marine environment in which strategic minerals and CRM make associated commodities, e.g. REE in bauxite deposits and manganese nodules; cobalt in nickel deposits and ferromanganese crusts; vanadium in iron-titanium deposits; indium and tellurium in VMS and epithermal gold deposits. For example, based on the ProMine mineral database European deposits were classified to 16 ore types along with related major and associated commodities (Tab.8).

- Secondary resources, in terms of historical and modern mineral-based mining wastes (waste rocks, processing tailings, metallurgical residues) and by-products, e.g. REE in apatite concentrates related to iron extraction and red mud derived from alumina refining; indium in the waste streams of lead-zinc sulphide mining. The ProMine database of mineral-based

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anthropogenic concentrations shows elevated concentrations in strategic and critical minerals which may reach feasible enrichments. The project focused on the largest anthropogenic concentrations and on those of greatest interest in terms of volume/tonnage and content (i.e. possible presence of strategic and critical minerals). The aim was to have an inventory, as complete as possible, of concentrations which could be processed for the recovery of strategic/high-tech/critical commodities (Fig. 25). However, it was beyond the scope of ProMine to compile a comprehensive inventory of wastes throughout Europe.

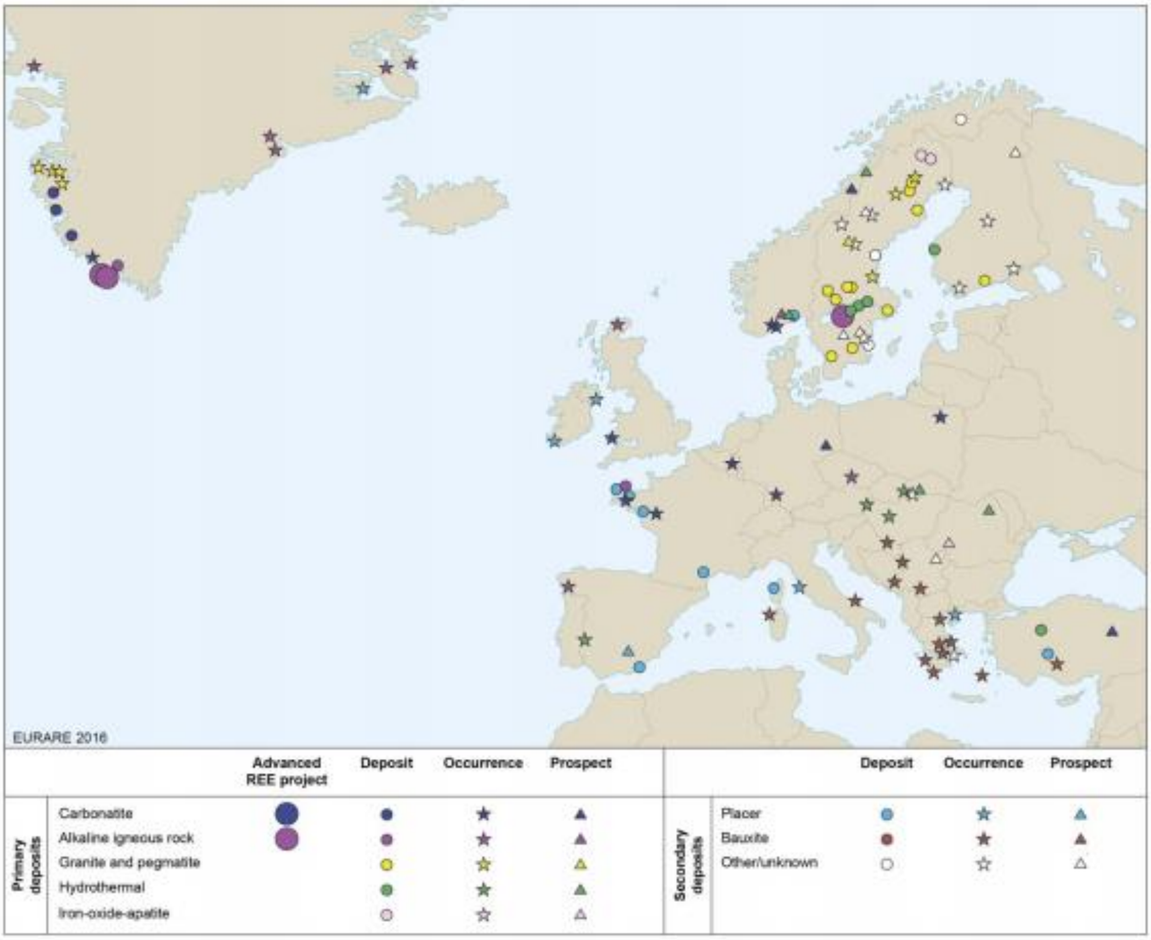

Fig. 24: Location of mineralisation and deposit types in Europe (Source: EURARE)

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Tab.8: Major types of European mineral deposits showing associated strategic commodities (Source: ProMine)

Number	Deposit types	Commodity Association
1	Alkaline & Peralkaline intrusions	Nb, REE, P, (Ta, Zr, Sc, F, U, Fe)
2	Epithermal	Au, Ag, Sb, Hg, Te, Cu, In
3	Igneous Felsic	Sn, W, Ta, Nb, (Mo, Li, Be, B, In, F)
4	Igneous Intermediate	Cu, Mo, Au, (Re)
5	Igneous Replacement	Fe, W, Pb, Zn, Cu, Au
6	IOCG	Fe, Cu, Au, (P, REE, U, Co)
7	Mafic intrusion	Fe, Ti, V
8	Mafic or Ultramafic	Ni, Cr, Cu, PGE, (Co, Bi, U, Ag)
9	Orogenic Gold	Au, (Ag, As, W, Cu, Sb, Bi)
10	Pegmatites	Nb, Ta, Sn, Li, Be, (U, REE)
11	Carbonate-hosted deposits	Zn, Pb, Ag, Ba
12	Sandstone- and shale-hosted deposits	Cu, U, Pb, (Ni, Co, Zn, V, PGE, Re)
13	Sedimentary deposits	Fe, Mn, Ba,K,Na,Sr
14	VMS	Cu, Zn, Pb, (Ag, Au, Te, Sn, In)
15	Residual deposits	Fe, Al, Ni, Cu, (Mn, Au, P, REE)
16	Base metals veins	Pb, Zn, Cu, U, (Ba, F)

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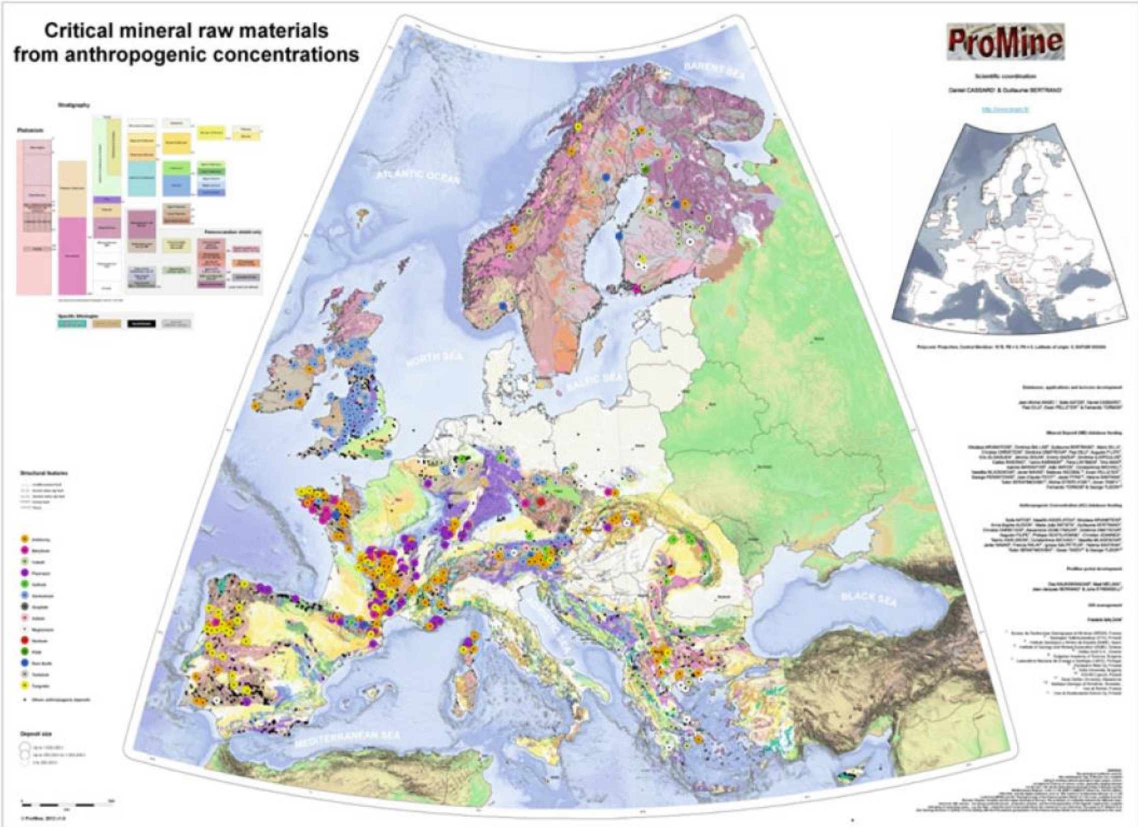

Fig. 25: Mineral-based wastes in Europe based on ProMine's anthropogenic concentrations' database with a special attention to sites containing critical mineral raw materials

5. Resource classification/potential

The application of UNFC calcification system will be tested as a tool to estimate the resource potential of strategic minerals in Europe, where collected data are well documented and reliable. Full European implementation of UNFC may provide more accurate forecasts on known prospects and solid resource figures on fully assessed deposits. The target will be to use some case studies to obtain Pan-European resource estimates on strategic minerals implementing the UNFC as a standard tool. Similar exercises on gross estimates on aggregated tonnages for the EU were carried out in ProMine project using both the mineral (Tab. 9, 10) and the anthropogenic concentrations (Tab. 11) databases.

6. Map products of deposit types, metallogenetic/mineral belts

The availability of well-documented databases and related information will make possible the delivery of digital map services and products. Using again the ProMine example, the map of major mineral deposits in Europe (Fig. 26) was created based on the classification types shown in Tab. 8, as well as the one of Fig. 25 showing the CRM found in anthropogenic concentrations. Another

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example is the CRM map of Europe (Fig. 27) using the mineral inventories of ProMine and Minerals4EU. Metallogenetic maps and

related interpretations, focused on strategic minerals will increase the knowledge on the CRM endowments and resource potential in Europe and to some extent the EU seas. The metallogenetic of the Fennoscandian Shield based on the FODD database makes an excellent example in that direction (Fig. 28).

Tab. 9: Statistics on the main metallogenic types found in EU and their tonnage (endowment) for their three main commodities (by order of decreasing frequency within the deposit type) (Source: ProMine)

Metallogenic type		Number of deposits	Ratio of commodities with documented potential (%)	Commodity 1		Commodity 2		Commodity 3	
Type number	Name			Name	Total tonnage	Name	Total tonnage	Name	Total tonnage
1	Alkaline and peralkaline intrusions	30	34.1	U	95,892	REE	718,948	Nb	778,963
2	Epithermal	512	27.9	Au	2051	Ag	19,199	Pb	2,694,389
3	Igneous felsic	890	17.8	U	113,888	Sn	1,284,825	W	300,861
4	Igneous intermediate	131	35.6	Cu	41,168,901	Au	1939	Ag	18,406
5	Igneous replacement	390	42.6	Zn	14,384,048	Pb	21,141,522	Fe	244,433,280
6	IOCG	67	78.4	Fe	2,538,790,905	Cu	567,297	Mn	1,107,910
7	Mafic intrusion	45	72.0	Ti	171,207,562	V	373,052	Fe	325,582,230
8	Mafic or UltraMafic	641	47.5	Cu	2,625,595	Ni	2,682,432	Co	124,389
9	Orogenic gold	514	20.8	Au	1309	Cu	399,129	Ag	6,892
10	Pegmatites	349	7.3	Li	307,713	Feld	4,266,023	Be	680
11	Carbonate-hosted	641	19.6	Zn	34,832,297	Pb	9,404,228	Fe	427,871,659
12	Sandstone- and shale-hosted	322	31.3	U	438,927	Cu	92,663,587	Pb	2,119,515
13	Sedimentary deposits	630	35.9	Fe	8,501,259,818	Mn	14,752,044	Ni	3,531,669
14	VMS	820	54.6	Cu	27,240,890	Zn	79,963,991	Ag	59,925
15	Residual deposits	588	24.3	Al	933,038,160	Fe	239,478,322	Ni	6,227,977
16	Base metals veins	1947	21.7	Pb	17,859,114	Fl	36,033,304	Brt	31,647,820

Tonnage (endowment) is expressed in metric tons. Total number of deposits: 8994, representing 69.3 % of the database (12,979 deposits). Other deposits are either of undefined metallogenic type (insufficient information for establishing the type), or belong to the 'Rocks and Industrial Minerals' group, or to the 'Energy Commodities' (e.g. coal, oil and gas …) group or to minor types

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Tab. 10: Statistics on the main commodities in EU and their tonnage (endowment: resources + reserves + past production) (Source: ProMine)

Type	Commodity	Criticality	Class A		Class B		Class C		Class D		Σ Tonnage	World mine production,	Equivalent number
		(EU list)	No. of deposits	Σ Tonnage	No. of deposits	Σ Tonnage	No. of deposits	Σ Tonnage	No. of deposits	Σ Tonnage	(classes A to D)	in tons of commodity (2010, Index Mundi estimate)	of years of world production
Precious metals	Ag		5	185,444.4	17	72,933.7	44	42,102.5	94	21,581.1	322,061.7	23,100	13.9
	Au		1	700.2	17	2,826.2	86	2,563.7	164	628.8	6,718.9	2,560	2.6
	PGMs	yes			1	523.6			2	5.7	529.3	466	1.1
Base metals	Al				2	2.94E+08	13	5.45E+08	18	81,156,000	9.2E+08	41,200,000	22.3
	Cu		3	55,826,080	26	65,278,601	68	21,181,016	219	7,591,200	1.5E+08	16,000,000	9.4
	PbZn		3	51,290,000	63	120,717,118	297	64,552,035	425	12,979,515	249,538,668	16,140,000	15.5
	Sn		2	3,266,000	14	1,405,268	22	112,764	18	6,554.6	4,790,587	265,000	18.1
Iron and ferro-alloy metals	Co	yes			3	504,4	34	342,744.4	52	35,811.2	882,955.6	89,500	9.9
	Cr		1	39,500,000	5	46,530,000	4	11,051,694	7	3,233,300	1,00E+08	23,700,000	4.2
	Fe		2	2.42E+09	28	7.96E+09	101	3.1E+09	198	6.76E+08	1.42E+10	1,280,000,000	11.1
	Mn		1	1.16E+08	1	10,750,000	14	53,206,990	31	8,391,079	1.89E+08	14,200,000	13.3
	Mo				5	843,148.6	11	223,339	9	23,117	1,089,605	242,000	4.5
	Nb				1	750	1	25,2	1	3,496	778,696	62,900	12.4
	Ni	yes	3	9,115,000	4	2,823,900	36	3,699,562	61	489,138.5	16,127,601	1,620,000	10.0
	V		1	2,005,733	3	984,252.8	16	767,224.8	19	182,321.5	3,939,532	61,200	64.4
	W	yes			4	374,438.4	21	260,367	21	38,315.2	673,120.6	68,800	9.8
Speciality and rare metals	Be	yes			1	6,664	2	2,257	2	158.5	9,079.5	5,080	1.8
	Bi				2	6,115	2	900			7,015	16,000	0.4
	Cd		1	13,6	2	5,22	6	7,938	5	1,534	28,292	22,800	1.2
	Ga	yes			1	90	1	30	1	3	123	260	0.5
	Ge	yes	1	800	1	174	2	58	3	39	1,071	N/A	N/A
	Hf		1	28,628.9							28,628.9	N/A	N/A
	Hg		2	216			7	15,061	3	551.5	231,612.5	2,250	102.9
	In	yes	2	5,387			1	50	2	15.5	5,452.5	659	8.3
	Li		1	1,280,000	1	215	2	116	4	67,012.8	1,678,013	23,500	71.4
	Rb		1	19,5					1	1.8	19,501.8	N/A	N/A
	Re						1	60	1	43	103	47.,2	2.2
	REE	yes	1	5,675,013	1	446,85	2	110,426	1	8,447	6,240,736	123,000	50.7
	Sb	yes			8	366,341	36	271,177.4	11	13,163	650,681.4	167,000	3.9
	Se						1	433.4	1	52.5	485.9	1,980	0.2
	Ta	yes			2	39,25	1	1,95	3	790.3	41,990.3	682	61.6
	Ti		1	73,440,000	18	1.27E+08	15	11,116,382	9	743,855	2.12E+08	2,210,000	95.9
	Zr		1	1,588,800	5	1,503,200			2	11,381	3,103,381	1,250,000	2.5
Minerals for chemical use	Brt		4	49,362,400	17	37,159,000	32	14,652,350	20	1,971,813	1.03E+08	7,850,000	13.1
	Fl	yes	6	52,621,000	10	20,061,620	21	9,722,000	29	3,330,705	85,735,325	7,180,000	11.9
	Mg	yes	1	2.1E+08	2	39,215,439	10	29,072,080	10	3,593,800	2.82E+08	755,000	373.5
Speciality and other industrial rocks and	Graphite	yes	1	12,300,000	2	2,677,500	6	1,493,200	5	181,88	16,652,580	925,000	18.0

Tab. 11: Statistics on critical mineral raw materials from anthropogenic concentrations (Source: ProMine project)

Commodity	Total no. of sites	Number of sites with calculated potential	∑ potential (t)
Be	36	9	41
Co	131	62	39.656
Ga	59	28	8.82
Ge	157	18	408
In	36	7	4.273
Mg	42	27	17,147,091
Nb	18	8	379
Pt	5	1	0.6
REE	13	5	13.755
Sb	198	37	78.299
W	124	23	15.137

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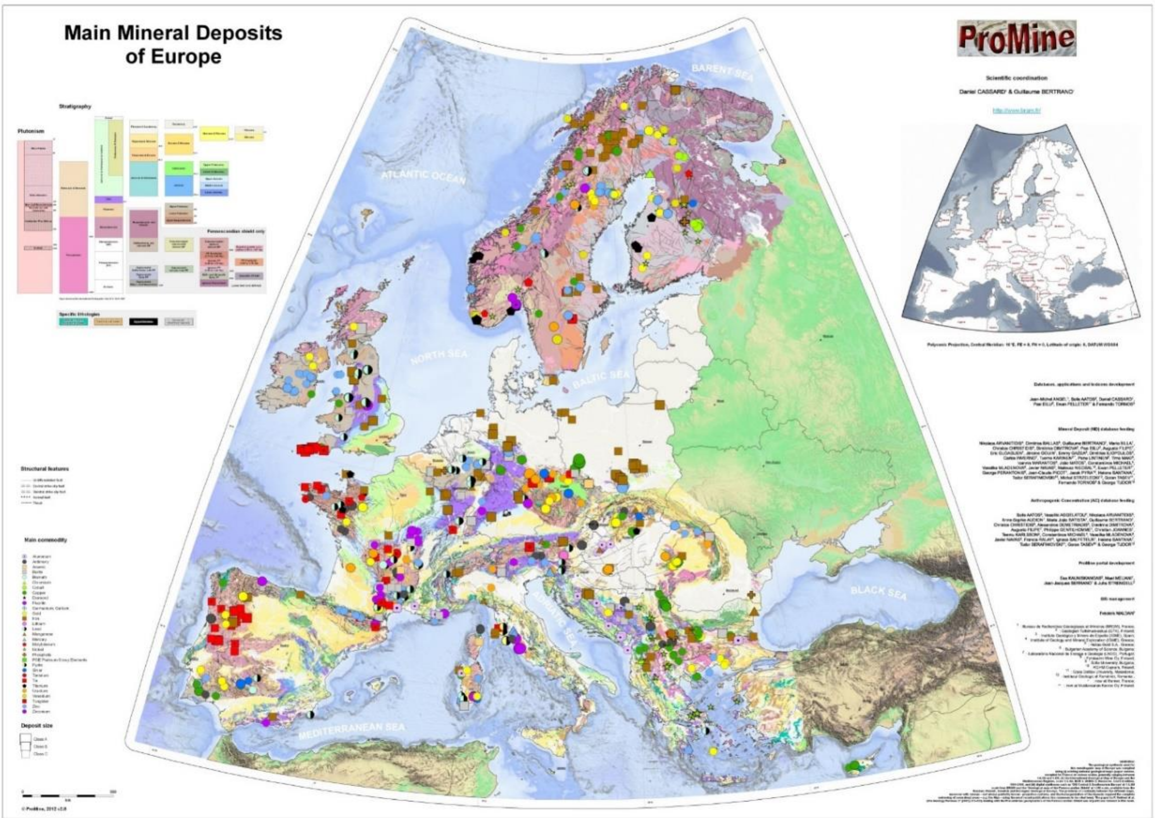

Fig. 26: Map of the major mineral deposit types in Europe (Source: ProMine)

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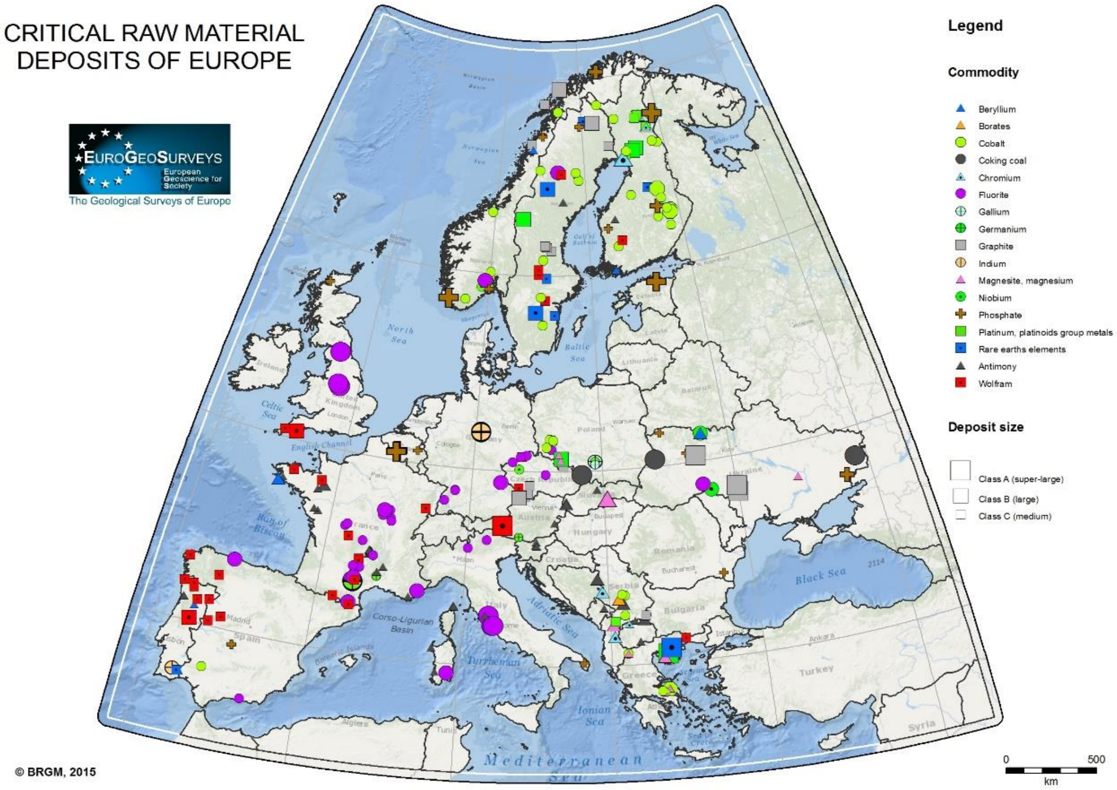

Fig. 27: Map of CRM in Europe (Source: ProMine; Minerals4EU).

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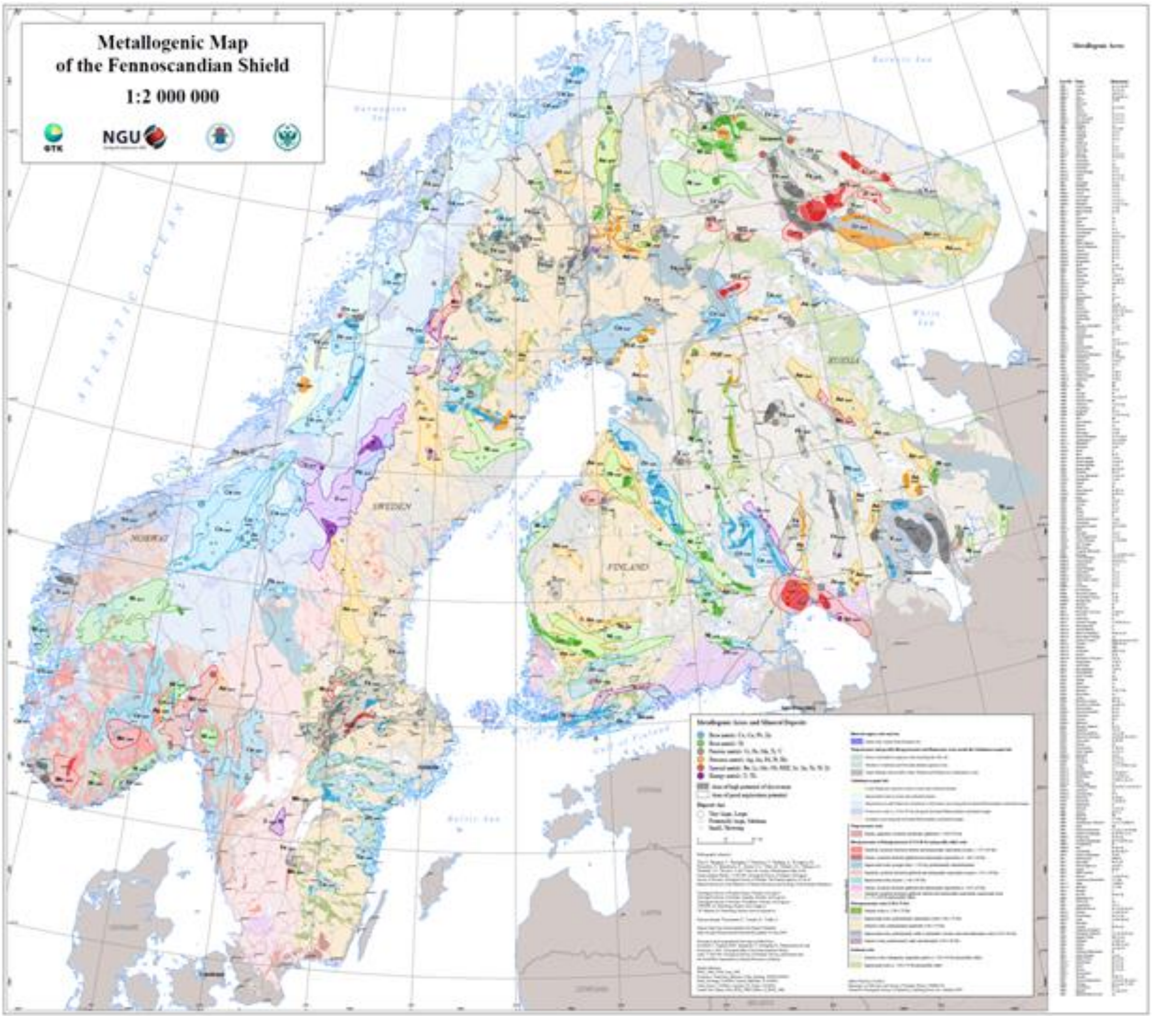

Fig. 28: Metallogenetic map of the Fennoscandian Shield (Source: FODD)

7. Predictivity/Exploration potential

As mentioned in other parts of this report, the FRAME project, and particularly WP3, will build on previously and currently collected pan-European and national databases, and expand the strategic minerals knowledge trough a compilation of mineral potential and metallogenic areas of critical raw materials related mineral resources in Europe, focused on related metal associations on land and the marine environment. Secondary resources, in terms of historical mining wastes and potential by-products will also be considered. The mineral resources targeted will have to extend beyond the current EU CRM list and include also minerals (Tab. 4) that are strategic for the European downstream industry in the long-term perspective. In this respect predictive mapping and modelling, based on GIS multidisciplinary tools, will be performed to generate new targets of high exploration potential and outline strategic minerals' metallogenetic

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provinces, define prospective strategic mineral belts and re-assess the feasibility of mining districts and brownfields where strategic minerals are found as associated commodities. Examples of strategic minerals' predictivity approach were presented by ProMine.

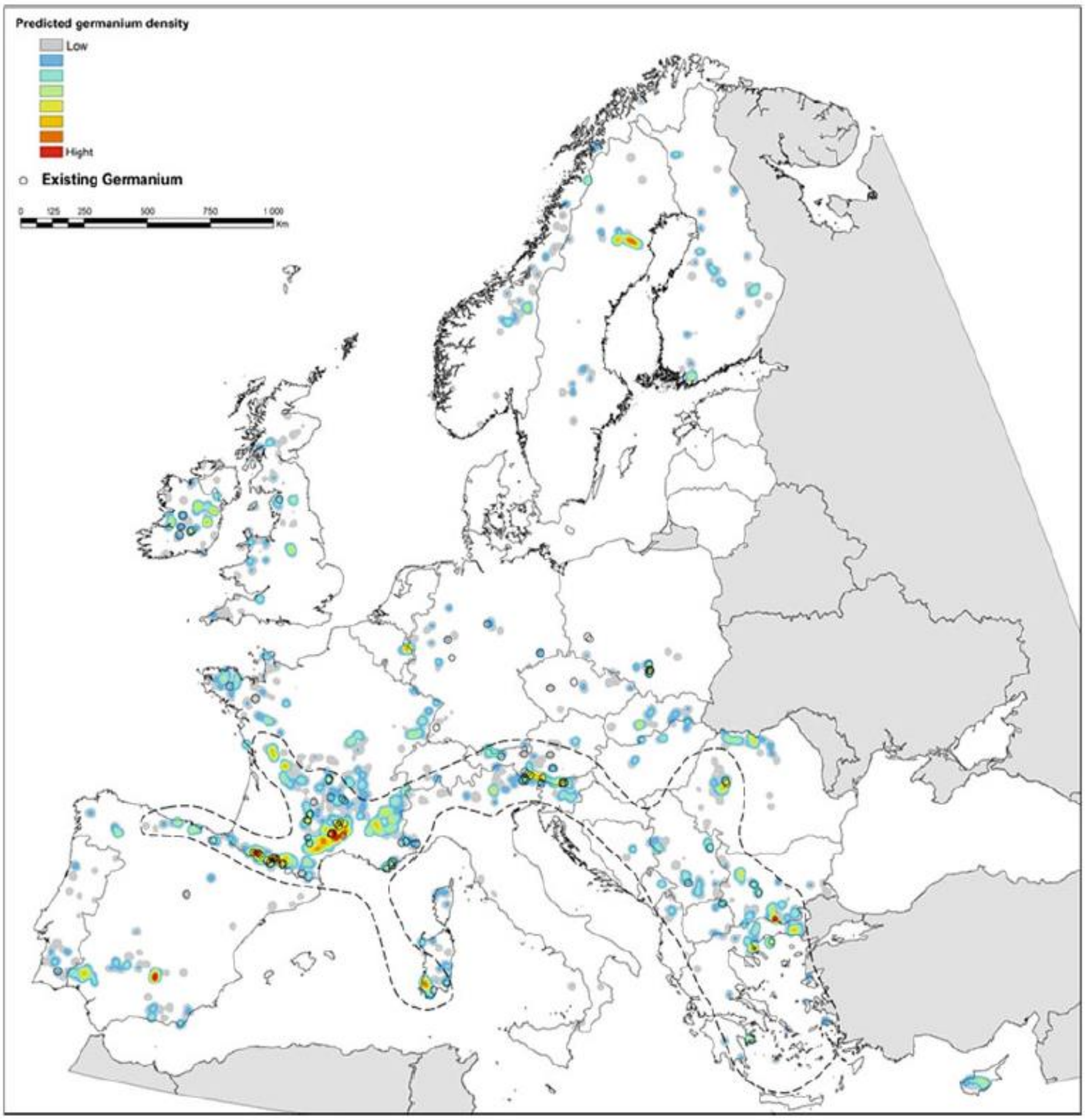

Fig. 29: Predictive map for germanium, obtained from the ProMine database.

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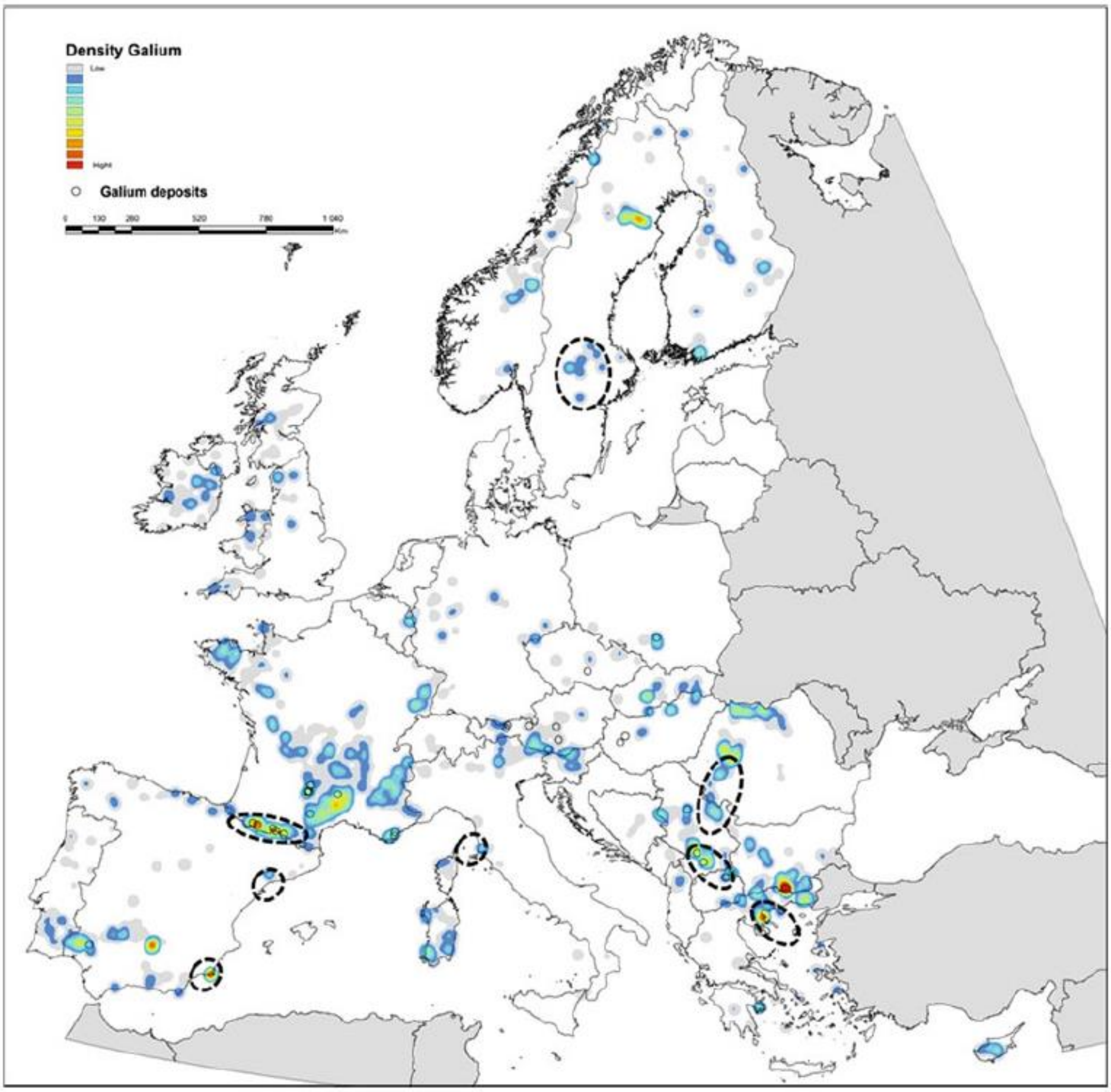

Fig. 30: Predictive map for gallium, obtained from the ProMine database.

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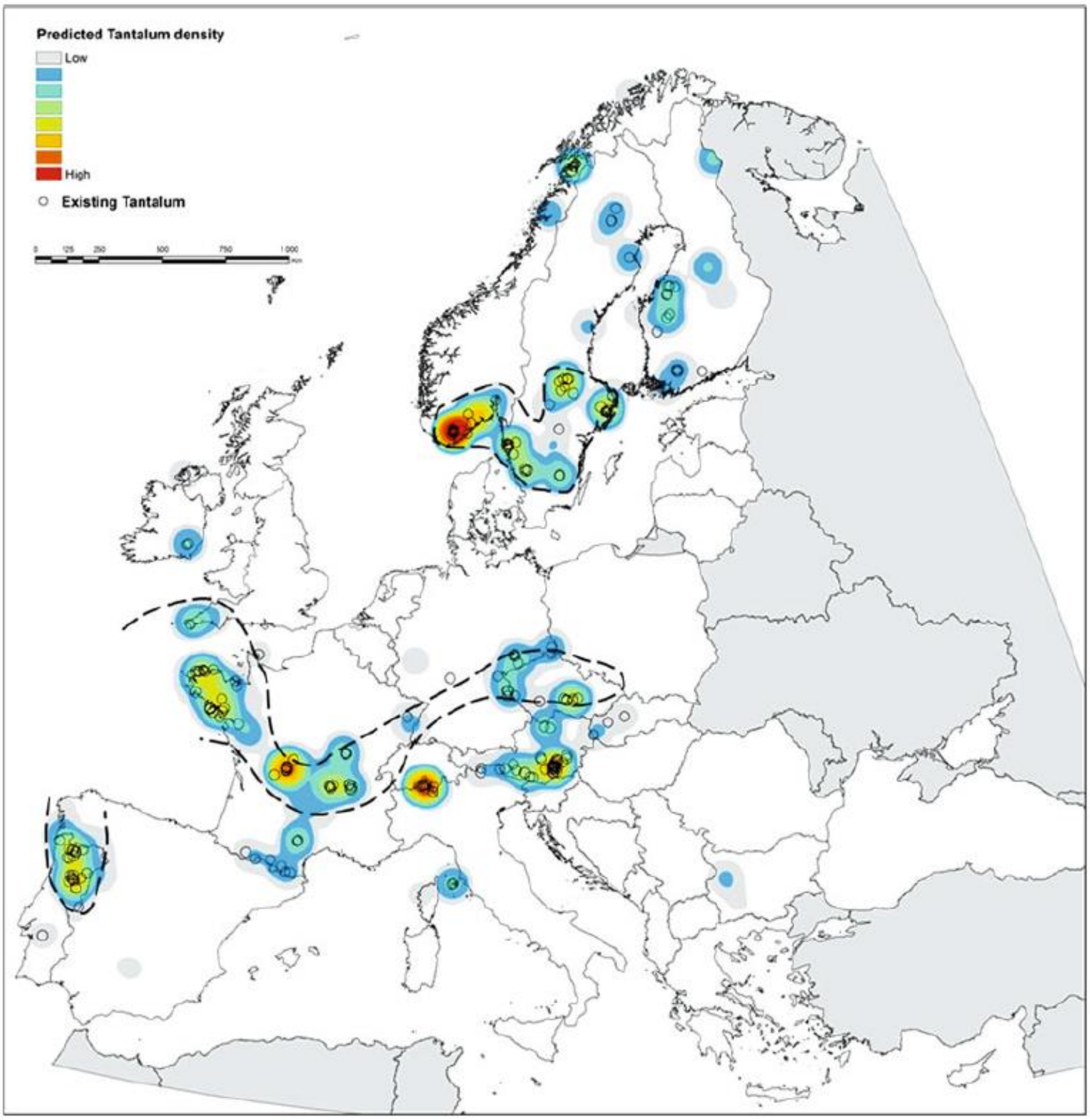

Fig. 31: Predictive map for tantalum, obtained from the ProMine database.

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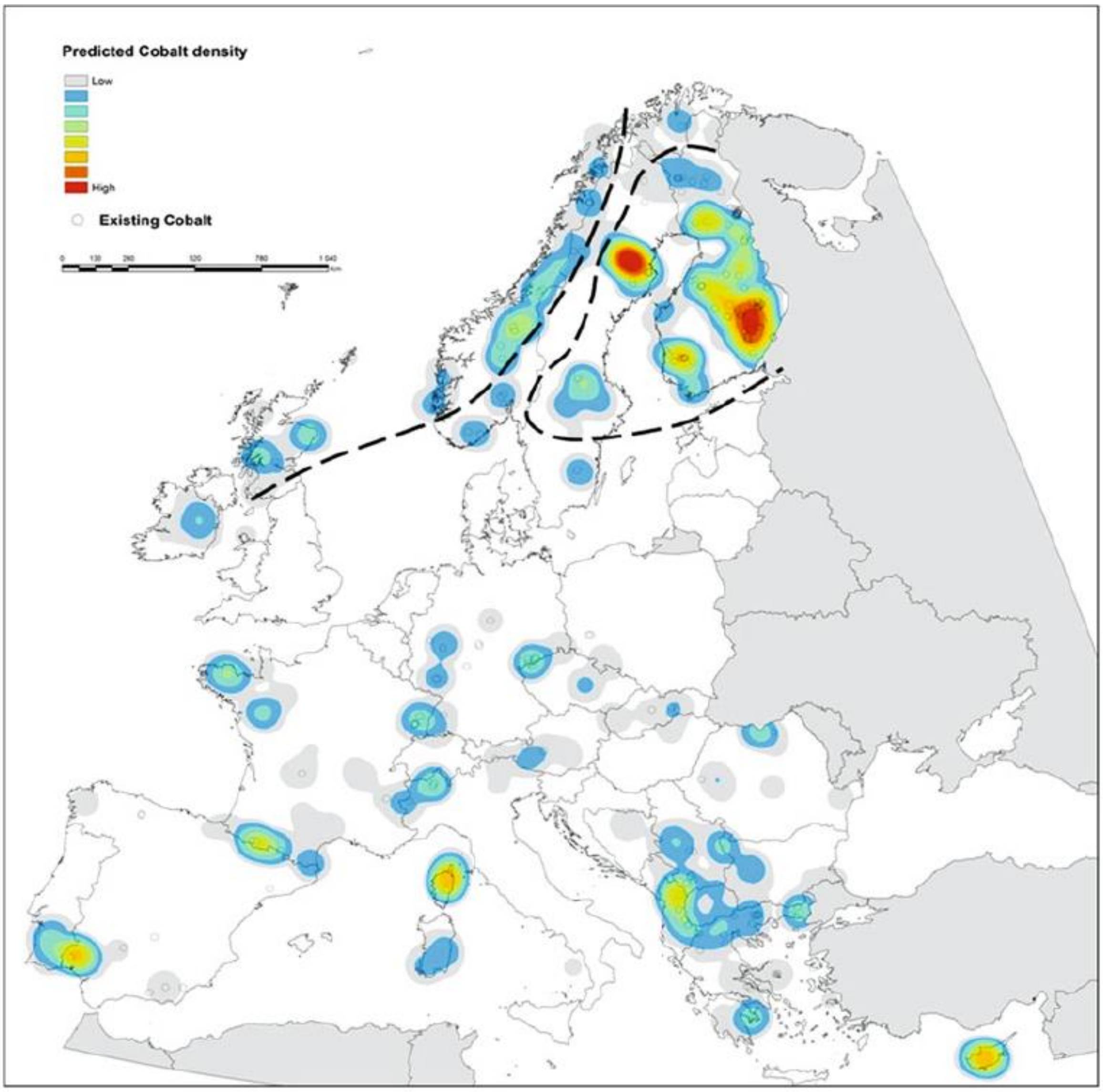

Fig. 32: Predictive map for cobalt, obtained from the ProMine database.

8. Conclusions

Carrying out the anticipated tasks by using the methodology and the tools mentioned above, WP3 will contribute in,

- Contributing to creating the FRAME strategic minerals database and information platform.
- Providing a data platform, digital version of mineral deposit types and metallogenic map, and related description report, highlighting the endowment and exploration potential of strategic minerals in Europe.

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- Producing predictivity maps outlining the strategic minerals exploration potential areas and the major prospective minerals belts.

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Appendix

WP3: Critical and Strategic Raw Materials Map of Europe

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