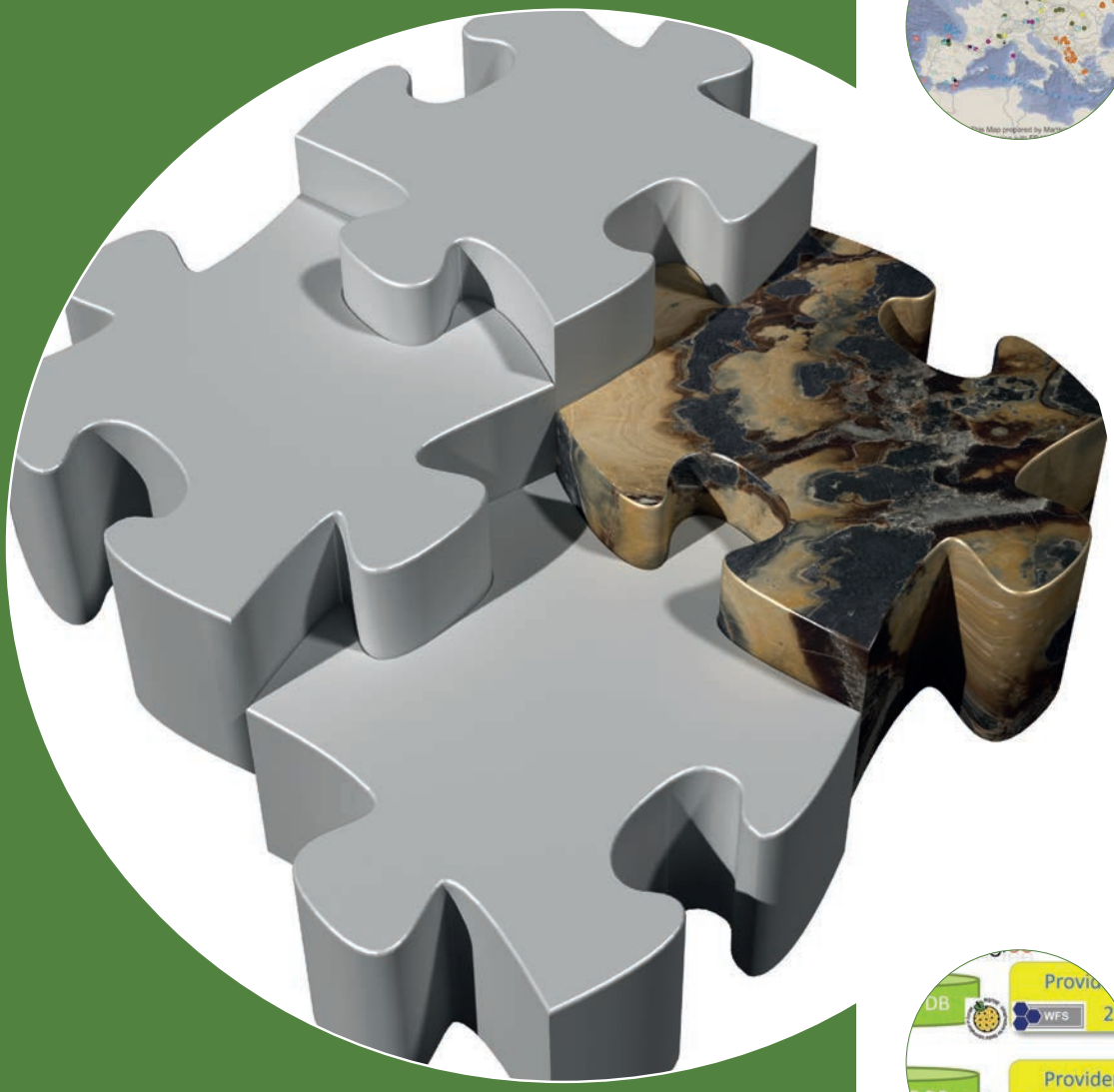

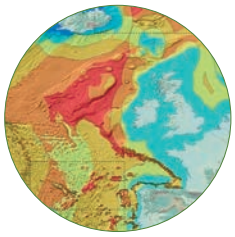

Monograph

GeoERA Raw Materials

– the past and the future –

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Layout and Graphics: Jolante Duba, Antje Wittenberg

ISBN: 978-3-9823438-6-0

DOI: 10.25928/geoera_rawmat22_1

How to cite: Antje Wittenberg, Daniel de Oliveira, Lisbeth Flindt Jorgensen, Francisco Javier Gonzalez, Tom Heldal, Kari Aslaksen Aasly, Eimear Deady, Špela Kumelj, Henrike Sievers, Zoltan Horvath, Eoin McGrath (2022): GeoERA Raw Materials Monograph – the past and the future. – 141 pp, Hannover, Germany"

Monograph

GeoERA Raw Materials

– the past and the future –

Contents

List of Figures

List of Tables

Foreword

The ERA-Net on establishing the European Geological Surveys Research Area to deliver a Geological Service for Europe (GeoERA) was established in 2017 bringing together 45 national and regional Geological Survey Organisations from 32 European countries to collaborate in a joint geoscientific research program, the first of its kind in Europe. The vison of the GeoERA program was to establish the basis for a common European geological knowledge base and to encourage joint research and support of European policy priorities.

Prof. Dr. Ralph Watzel, *President of the Federal Institute for Geosciences and Natural Resources (BGR) and acting president of EuroGeoSurvey.*

As underlined by keynote speakers and panellist at the final event of GeoERA, the importance of harmonised data and information to policy and decision making processes as well as the need for public awareness and the need for good communication to the citizens. The feedback received from external stakeholder supports the impression GeoERA is a real success based on sound scientific research.

GeoERA is an important milestone on the way to further harmonization of geological knowledge and cooperation in Europe. This success has been made possible by a well-established network of experts – in the GeoERA Raw Materials thematic field many of whom are also organised in the EuroGeoSurvey Mineral Resource Expert Group (MREG).

Geological Raw Materials cover a wide range of commodities ranging from sand and gravel to ornamental stone (granites and marbles) to metals (precious, ferrous and base) and minerals, including those that are described as being critical. The history of society is described by how humankind interacts with available geological resources and the developmental stages of civilisation are recognised according to the mineral resources which enabled technological and societal development. The Stone Age, Bronze Age and Iron Age are explicitly linked to minerals, while progress through the industrial revolution, the modern industrial age and into the computer age were reliant on coal, oil and silicon respectively.

Gradually, the diversity of geological resources exploited to serve human technology development has increased, and virtually every element of the periodic table has a modern industrial use. The current transition to a low carbon and renewable energy future is based on key raw materials of strategic importance. The European Commission has developed a dynamic list of Critical Raw Materials (CRM) which are essential in key industry sectors but are subject to significant supply risks. In recent years, access to CRM has evolved into a strategic security question for Europe's road towards the green transition.

GeoERA Raw Materials is active in this environment and has developed many targeted products to improve the European knowledge base and support future decision-making processes.

Prof. Dr. Ralph Watzel, President of the Federal Institute for Geosciences and Natural Resources (BGR) and acting president of EuroGeoSurvey.

Scott Foster
Director, Sustainable Energy Division, UNECE

Resource industries face an image and reputation challenge as they often are seen as drain industries that extract wealth and leave social and environmental problems in their wake. A number of critical issues must be addressed if the resource industries are to meet what is expected of them over the coming decades. The UN's 2030 Agenda for Sustainable Development is about meeting quality of life aspirations globally. Resources will be required to deliver on the range of Sustainable Development Goals, which means investment, the production, distribution, and use of resources must be managed sustainably.

A critical issue for resource industries is a rapidly increasing material footprint. Resources are in some cases scarce, in others they are hard to extract and process and there is concern regarding security of supply; climate change is an existential threat, and management of resources must address all environmental impacts. The current resource model – linear with lots of waste and little re-use is often wasteful, inequitable, and socially, environmentally, and economically damaging. Instead of the "use and discard" commodity model, resources should embrace circularity by design.

UNECE has proposed action on a five-point framework for resource industries that would include: (i) development of a proper social contract; (ii) agreement on common sustainable finance principles and taxonomy; (iii) deployment of a sustainable resource management system; (iv) implementation of a framework for traceability, transparency, and sustainability of resource supply chains; and, (v) strategic environmental assessments of plans and programmes. UNECE tools such as the existing United Nations Framework Classification for Resources (UNFC) and the United Nations Resource Management System (UNRMS) under development have at their core the sustainable development triad of society, environment, and economy. Our work in this area is conceived to mobilize the investments that are needed to secure the resources for a sustainable future and that meet the needs of local communities.

UNECE has been very pleased to support the GeoERA Project, including the Raw Materials component. In turn our work to develop and deploy UNFC, a universally acceptable and internationally applicable scheme for the sustainable management of all energy and mineral resources, has benefited from the extensive testing undertaken by GeoERA partners. The success with UNFC that we see today is a result of our fruitful collaboration and we welcome the opportunity to continue our work together going forward. We are cooperating with partners to prepare UNRMS, a comprehensive, sustainable resource management system that supports the realization of the 2030 Agenda. Sustainable resource management is defined as the total of policies, strategies, regulations, investments, operations and capabilities within a framework of public, public-private and civil society partnerships, and based on environmental-socio-economic viability and technical feasibility, which determine what, when and how resources are developed, produced, consumed, reused and recycled by the society. Sustainable resource management using UNRMS is intended to optimize sustainable benefits to stakeholders within the people-planet-prosperity triad.

UNECE looks forward to building on the important legacy that GeoERA has left and to supporting the launch of a Geological Service for Europe. We believe we will be able to accelerate development and deployment of both UNFC and UNRMS through our close and continuing partnership.

David Ovadia *MBE, Chairman of Golden Metal Resources Ltd and former Director of International and Corporate at the British Geological Survey.*

We live in a complex and interconnected world in which humankind faces the challenges of pandemics, conflicts, natural hazards including those exacerbated by climate change and the constant struggle to improve living conditions and reduce poverty. Geological data does not exist in isolation in these contexts. It underpins the sometimes conflicting requirements to generate energy without increasing carbon emissions, to produce the raw materials for growth and quality of life and to help mitigate the threats from catastrophic earthquakes, landslips, tsunamis and volcanic eruptions.

Geodata have been collected and are held by many institutions, public and private, over a long period of time. The GeoERA Raw Materials initiative of the European Union creates valuable, accessible and public data and information for policy-makers and end-users of geological data and minerals information. The extractives sectors are viable only if they have access to high quality geodata. The exploration and mining companies that operate successfully usually have a global view; they can extract their minerals from almost anywhere in the world, raise investment funds in many international money centres and sell into world commodity markets.

European policy is to become self-sufficient in certain critical minerals that are necessary for strategic industries in pursuance of political, economic and environmental aims. To achieve this against global competition for mining investment and human skills, Europe must dismantle as many inhibitors as possible. Significant amongst these has been the fragmentation of public geoinformation which, for historical reasons, has been held in a variety of formats in the archives of national and sub-national geological surveys and other bodies. The GeoERA initiative intends, and to a high degree succeeds, in bringing those archives into a place that is easily and reliably accessible to mining companies when making their investment decisions. If high quality and relevant geodata are available for Europe, all other things being equal, mining companies and their shareholders will be attracted; if not then other parts of the world where data are more easily obtained will win in the competition for investment, jobs and exports.

The challenge now is to build on the success of GeoERA. This will require imaginative and flexible solutions to achieve post-project sustainability, efficient delivery and support mechanisms and enhancement of the data to include public and, where possible, privately held geophysics, geochemistry and non-geoscience cultural data such as licence availability, infrastructure and protected land. Many exploration and mining companies such as my own remain eager to consider investing in Europe provided the conditions, of which the availability and supply of geodata is important but not unique, are as favourable as those found in other continents.

GeoERA has made considerable progress in the right direction, and I commend its participants. If the strategic intentions behind it are to succeed, it should be seen not as a finished piece of work but rather as a solid foundation for further activities that will help to make Europe an attractive place for sustainable and responsible mining activities.

Disclamer

GeoERA Minerals projects have produced data aimed at supporting Europe's minerals sector and to assist the European Commission to realise its goals for raw materials. Data has been compiled on mineral occurrences and mineral provinces across Europe, in particular, areas with potential to host Critical Raw Materials.

Anecdotal evidence from the minerals sector provides an indication of the likelihood of exploration leading to mine development. For every 1,000 mineral showings examined, only 100 may receive further exploration work and of those 100, only 10 may warrant more detailed sampling either through trenching, drilling or other means and of those 10 only 1 may proceed to an evaluation through a full feasibility study which itself has only 50% chance of being positive. Following this, any project for which a mine proposal is made must undergo a full evaluation and permitting by authorities including full public consultation. The proposal may or may not pass this scrutiny. In terms of a schedule, the generally accepted minimum time frame from discovery to production is 10 years and usually much more, up to 20 years.

Information presented in GeoERA projects have been sourced from databases and information from mapping and exploration campaigns of individual Geological Survey Organisations and have been compiled to the best of our knowledge and in accordance with best practice guides.

GeoERA does not claim to be exhaustive, in terms of geographical coverage, nor does it replace a professional or entrepreneurial exploration campaign for project identification and/ or development. Any individual deposit or areas identified in any GeoERA report, should not be taken to be a location with proven potential or to be taken as a recommendation for additional investigation. Nonetheless, GeoERA has identified areas with potential, particularly for Strategic and Critical Raw Materials. This information may be useful for investment decision-making, which may lead to future mining activities, subject to the identification of an economic deposit and the receipt of all permits. Follow-up of individual deposits or areas identified in GeoERA projects, by entrepreneurs and/ or mining enterprises is required to prove the existence of an economic deposit and should only be undertaken by those knowledgeable of the risks involved.

It is GeoERA's opinion that the very ambitious target of the European Commission to realise new raw material projects by 2025 can only be achieved if projects have already received the necessary permits (early 2022).

Stakeholder statements:

- *GeoERA has, without doubt, produced outstanding results.*
- *The information compiled have a high potential in attracting interest to the natural stone area by several stakeholder groups and especially among spatial planners, heritage conservation authorities and politicians.*
- *Various stakeholders, including students, geologists, industry, spatial planners, authorities (national, regional and local), and politicians can benefit from the information gathered.*
- *The very successful project, forms a fantastic foundation layer for further development, with a lot of data usage potential*
- *This work is also laying the foundation for targeting in the near future the most accessible resources to be mined with a minimum environmental impact and represent a remarkable milestone in terms of the pan European seabed mineral deposits knowledge base.*
- *It forms a good foundation with easy access to useful and reliable mineral intelligence / data for the whole of Europe and this project has demonstrated that a new geo-vision could be possible for Europe.*

The project team is congratulated for their excellent work.

1 GeoERA – an introduction

The economic, environmental and social challenges for civilization are constantly increasing. The drivers for those challenges include a growing population[1] as well as the right to good living conditions for all. Many of these challenges are mastered on a technical level, while others are achieved through responsible behaviour on the part of everyone. Ensuring prosperity, common welfare within a healthy and safe environment for all citizens within Europe, places increasing pressure on the availability and exploitation of our subsurface natural resources, such as water, minerals and energy. Yet, the pressure on natural resources caused by humans remains high and requires specific attention. The discussion of climate change has also contributed to increased social awareness to what's referred to as 'growth limiting system boundaries' (Meadows et al, 1972).

The 17 Sustainable Development Goals of the United Nations (UN) provide common ground for actions that apply to water, energy, raw materials and data in order to achieve good living conditions for everyone. The UN points out that the multifaceted requirements of sustainable development are primarily dependent on the optimal and responsible use of natural resources. The UN also points to the fragmentation of actions while joint monitoring and assessment measures fall short (Aggestam et al, 2021). At the level of the European Union, sign-up to the Paris Agreement on Climate Change and the grand societal challenges are reflected in the European Green Deal and echoed by its subsequent strategies and actions (European Commission, 2019a). At the same time, there is a need to overcome fragmented approaches at the project-to-project and country-to-country level. This may be due to limited perspectives on behalf of some participants and / or varying degrees of data and information to support knowledge based decision making.

A prerequisite for knowledge-based decisions in the sense of the European Green Deal is a good understanding of the 'Earth System' based on relevant, detailed, reliable and comparable data and information. The provision of this information at regional and national level is among the tasks of Europe's Geological Survey Organisations (GSOs). On the other hand, the mandate and structure of individual GSOs differ significantly with consequent effects on their regional / national work and possibilities for international cooperation. In addition to this spatial national task, GSO scientists are well aware that geological systems rarely stop at political borders and that cooperation is required to fully grasp the complex geological puzzle. Thus, apart from the scientific interest, cross-border cooperation improves the quality of research and data and hence decision making. Individual projects have been worked on for a long time by likeminded colleagues from various GSOs, but capacity building and a systematic, continuous, reliable structural setting of collaboration cannot be established by this piecemeal approach. Geoscientists are well aware of this and are working towards comparable understandings on Europe's natural resources within a common database.

1 In November 2021 the world population was 7.7 billion people, each with a life expectancy of 73.2 years according to the United Nations (https://www.un.org/en/global-issues/population). The European Union population accounts for about 447 million people (European Commission, 2020a). Already today, the average age of 7.5 million Europeans and a life expectancy of 79.1 years is 43 years. This makes Europe an ageing society. (https://ec.europa.eu/eurostat/de/web/population-demography/demography/publications/demography-report). The United Nations Economic Commission for Europe (UNECE) acknowledged that population growth will also have asignificant impact on natural resources supply patterns.

Within the ERA-NET Co-Fund Action known as GeoERA whose long title is 'Establishing the European Geological Surveys Research Area to deliver a Geological Service for Europe (GeoERA)' GSOs are building a common pan-European data structure and database.

GSOs have previously worked together on common issues and in many projects. However, GeoERA is by far the largest consortium with 45 organisations working together on common goals. Although GeoERA did not start from scratch (work on a pan-European geological data structure had already commenced with the development of the European Geological Data Infrastructure (hereafter EGDI)), it is the first programme to develop steps towards a cross-border geological intelligence based on broad knowledge and experience of individual survey organisations. It is also supported by EuroGeoSurveys and its 12 Expert Groups. The geological intelligence is built on the personnel capacity of over 11,000 personnel within the 38 participating EuroGeoSurveys members (as of 2021) plus those coming from nine GeoERA partners that are not Member of EuroGeoSurveys. These figures are already an indication of the usefulness of tackling major challenges and issues of common interest in a coordinated manner to increase the efficiency of workforces and the impact of the gained knowledge beyond their own community.

The intention to establish subject-specific research and innovation in the applied geosciences with transnational relevance has a long history. It dates back to before 2012 when Article 185 of the Treaty on the Functioning of the European Union (as it became known following the Lisbon Treaty TEUF)[2], which permits EU Member States to participate in research programmes jointly, was identified and recommended by Directorate-General for Research and Innovation (DG RTD) of the European Commission as a vehicle for collaboration and cooperation between GSOs. With the EU Research Framework Programme of 2014 – 2020, also known as Horizon 2020, the conditions and preferences changed requiring the need to find an alternative solution to support collaboration. Learning from (government) models of other European institutes where transnational research and services are carried out and delivered, GeoERA adopted the ERA-NET Co-Fund format for which the European Metrology Programme for Innovation and Research (EMPIR) was a model.

Each multiannual Framework Programme of the European Union adjusts the priorities for action in research and innovation in order to support the agreed policies. Hence, the up-coming Framework Programme to be known as Horizon Europe (2021 – 2027) will have an impact on the research and science landscape. The call HORIZON-CL5-2021-D3-02-14 'Support to the activities of the European Geological Services' calls for a Coordination and Support Action (hereafter referred to as CSA) and acknowledge the efforts by the GSOs and forms one building block towards a joint programming and support infrastructure. The majority of GSOs will respond to that call while building on the results and operating experience gained within GeoERA. Thus, the knowledge gained within GeoERA goes beyond science and is intended to offer opportunities for operational and structured collaboration in future joint programmes.

2 European research partnering Instrument; in the public sector in Europe > 80 % of the research is funded at national level. A vital European research area requires coordinated and coordinated national and regional research programs for which ERA-NET might serve. Article 185 forms the legal basis for EU participation in jointly coordinated R&I programs aiming to increase the efficiency and effectiveness of programs.

The four GeoERA thematic areas, namely, GeoEnergy, Groundwater, Raw Materials and the Information Platform represent the nucleus that reflects regional and national needs and common interests combined with the requirements of the European Commission in the area of research and innovation in the geosciences. A total of 15 scientific projects were chosen following a competitive process and have been designed to support:

a) a more integrated and efficient management of geological resources;

b) a more responsible and publicly acceptable exploitation and use of the subsurface; and

c) an enhanced harmonized knowledge base in applied geoscience in Europe.

The scientific projects are designed to provide relevant information to assist policy and decision-makers at all levels of government, industry and other stakeholders, that face the challenge of sustainable and responsible sourcing and development.

1.1 Motivation and aims

This publication focuses on the GeoERA Raw Materials theme. At the turn of the millennium, many European players had withdrawn from activities in the upstream segment of the raw materials value chain and the belief in a fair and open market was high, while in Europe exploration and mining was often not very welcome. With the arrival of new players on the global market, the demand for commodities increased significantly and with it the competition for the available commodities (Mateus and Martins, 2021). The change in the market can be seen most clearly in the example of China, which very quickly became an important supplier (Wen et al., 2019). Thus, Europe has become almost entirely dependent on China for commodities such as rare earth elements (REE). That development was not only due to the geological availability of REE, but also due to the refinery and smelter capacities in China. At the same time, China used its profits to develop the country to the top position of today on a scale and at a speed previously unprecedented of. China's global geostrategic investments further exacerbate the competitive situation for the European economy (EPRS, 2021). Contemporaneously, technical development does not stop and the demand for products e.g. for the communication and telecommunications, in the transportation and energy sectors is ever since increasing and requires chemical element hardly used in the early 20th century (Nassar et al., 2015) [and for more see chapter 2].

Mineral raw materials are essential in our daily life, for our sense of well-being and for a prospering society (Figure 1.1). It is no exaggeration to say that raw materials form the backbone for our prosperity, health and wealth. Their supply relies heavily on well-functioning supply chains and good governance and management is needed now more than ever. Hence, raw materials have received increasing attention by a wider range of stakeholders with various interests and motivations. That well-functioning supply chains are critical is recently demonstrated by the COVID-19 pandemic (Gałaś et al., 2021; Jowitt, 2020; PWC, 2020). From pharmaceuticals, medical or smart devices to green technologies and products none of these associated supply chains can function without mineral raw materials, and supply chains cannot be taken for granted.

However, the pressure on the demand side will grow with growing world population, ageing society in Europe, increasing consumption by growing nations especially in Asia and Africa. The United Nations sees raw materials as the key component for achieving all 17 Sustainable Development Goals. The European Green Deal (European Commission, 2019a) as well as the Paris Agreement cannot be achieved without raw materials of which many are considered to be critical in the European economy.

Several forecasts and scenarios have been put forward from various perspectives - economic, social, cultural and ecological – for raw materials. They all have in common that pressure on the demand side will remain high

(e.g. Schönbauer et al., 2014; Sverdup et al., 2017; Wellmer et al., 2019; Nassar et al., 2020). The Global Resources Outlook 2019 of the International Resource Panel (IRP), for example, foresees an increasing demand for raw materials worldwide regardless of all efforts to further close the raw material cycles (IRP, 2019). At the same time, the demand for responsible procurement under ethically, socially and ecologically sound conditions is becoming more and more vocal.

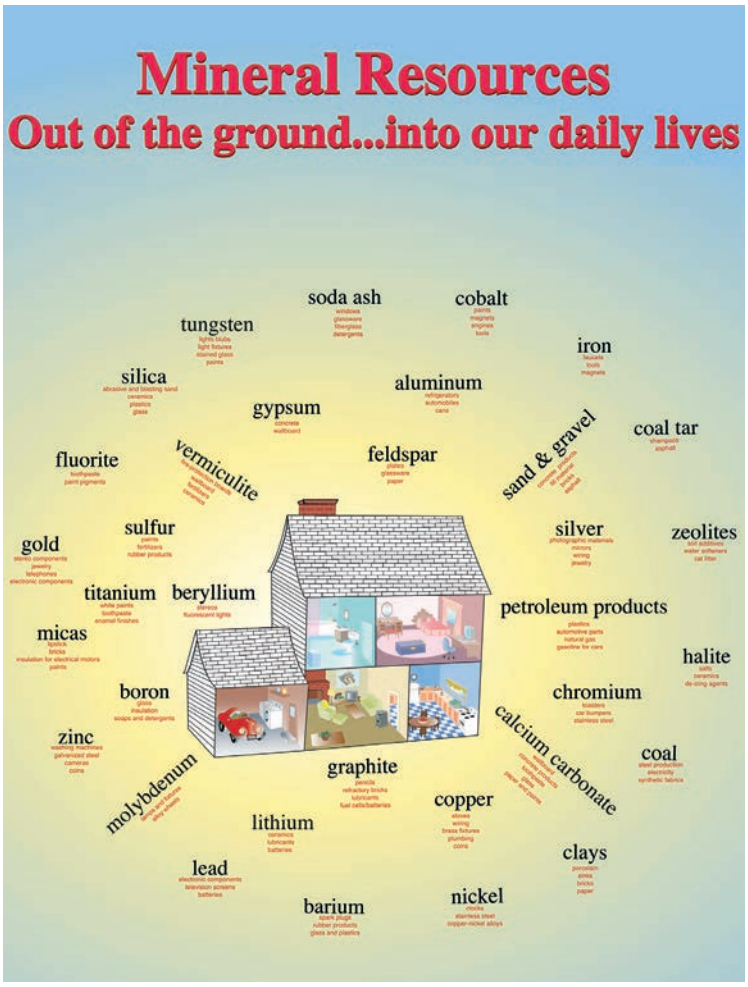

Figure 1.1: Raw materials in our daily lifes. Modified after Frank et al., 2001, USGS; accessible on https://pubs.usgs.gov/of/2001/0360/.

GeoERA Raw Materials reminds us of Europe's long tradition in quarrying and mining that today is only active in some regions. The re-evaluated potential of historical mining sites and new areas may assist in reducing Europe's vulnerability and add to the security and sustainability of mineral raw materials supply from EU domestic sources at the start of the value chain. GeoERA Raw Materials assists in predicting and identifying high mineral potential areas that may add to responsible sourcing and supply within Europe. The four GeoERA Raw Materials projects EuroLITHOS, FRAME, MINDeSEA and MINTELL4EU share expertise, information and focus on European on-shore and off-shore resources as a first step to take our share of responsibility to ensure responsible sourcing from domestic sources (Wittenberg et al., 2020; 2021).

About 45 National and Regional GSO´s and Marine Institutes have shared expertise and information improving what is called by the European Commission the 'EU Raw Materials Knowledge Base' (EURMKB). It is among the tasks of the GeoERA Raw Materials projects to show and evaluate, in a comparable way, the raw materials under our feet and to share these in accessible databases, and to visualize them in maps and scientific publications.

GeoERA Raw Materials was developed to support EU raw materials policies and the European Union's overall goal of ensuring a high quality and equitable life for all. Some of the European GSOs are very experienced and successful on the Brussels circuit, being members of fora and committees, providing 'Seconded National Experts' (SNEs) and in the acquisition and implementation of EU projects (see also 1.2.1). For other geological seconded national experts services, this is often still new territory and the requirements and wishes of the European Commission are unfamiliar. But the technical possibilities, the professional orientation and the depth of detail in research, development, innovation and consulting are also implemented heterogeneously in the geological services. Hence, workshops and training courses underpin the cooperation and add to capacity building in the EU aiming to overcome shortfalls in the community.

The issue of raw material supply in the EU has received much attention over the last decade. Assessments of the development of both the demand and supply sectors are discussed from various angles. However, forecasts

are always characterised by great uncertainty and imprecision. The motive of GeoERA Raw Materials is to improve the situation at least in the first part of the raw materials value chain. GeoERA Raw Materials makes this more reliable through increased data quality and its harmonisation in the area of forecasting undeveloped raw material deposits in Europe.

1.2 Building blocks

The European Commission examined the supply situation of the European Union in response of sharp price rises and the final declaration of the 10th UN General Assembly, providing a set of recommendations still valid today (European Commission, 1975). In September 2020, the European Commission published for the fourth time its list of Critical Raw Materials (hereafter CRM see Section 2.1) accompanied by a strategy to enhance 'Europe's Critical Raw Materials Resilience' acknowledging that most of these substances are sourced from other continents, and as global competition for them is increasing (European Commission, 2020b). The strategy lays down 10 actions aiming, among other things, to 'strengthen the sustainable and responsible domestic sourcing and processing of raw materials in the European Union'. Although Europe has a long tradition of mining and extractive activities, there are several challenges to establishing a robust and sustainable sourcing of raw materials in Europe. Challenges include lack of interest in investments in mining in Europe, permitting procedures for mining developments in Europe, and low levels of public acceptance of mining. Some of these are comprehensively addressed by the 10 Actions of the European Commission (European Commission, 2020b). The European Commission, again in 2021, identified the demand for strategic and critical raw materials in its Communications on the 'New Industrial Strategy' and 'Fit for 55' (European Commission, 2021a; 2021b).

There is significant potential for CRM in Europe from a geological perspective. However, a more harmonised knowledge base across borders is needed. Indeed, based on harmonised science-based information, mineral exploration and product manufacturing could be stimulated. This is where the GSOs of Europe play an important role as they are key partners in collecting and storing information on raw materials at the national level.

1.2.1 Networks, fora and partnerships

The European Commission has the right to propose EU-wide projects, programmes and legal frameworks. In preparing these proposals, recourse is made to a variety of fora, networks and partnerships in which the geological services are also represented, either through representatives of EuroGeoSurvey and its Mineral Resources Expert Group (MREG) in particular or as individual national GSO providing expertise to support the decision-making process. Since 2009, GSOs have been supporting the Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, DG GROW, of the European Commission, which is responsible for raw materials, through national expert secondments. In their function as public bodies GSOs are often involved in the European decision-making process, either directly as a representative of their own country or indirectly as an advisor to the national government or as representatives of EuroGeoSurveys. In addition to the 'Raw Materials Supply Group (RMSG)' and its Ad-hoc Working Groups setup by DG GROW several networks and partnerships have been developed that underpin European Commission actions in a knowledge triangle that stretches from science, academia and education; over business and industry; to administration and government. The following lists the most relevant who also provide research funding.

- **The EIP RM** (European Innovation Partnership on Raw Materials, https://ec.europa.eu/growth/sectors/raw-materials/eip_en), set up by the European Commission (DG GROW) in 2011, brings together representatives from the entire research and innovation value chain. Representatives from industry, public service, academia and Non-Governmental Organisation (NGOs) provide high-level guidance to the European Commission, EU countries and private bodies on innovative approaches to the challenges related to raw materials. The EIP's strategic implementation plan (SIP) sets specific goals and targets, that can be realised though EU or national/regional funding programmes.

- **EIT Raw Materials** (European Institute of Innovation and Technology on Raw Materials, https://eitrawmaterials.eu/) was established by the European Commission (Directorate-General for Education, Youth, Sport and Cultur (DG EAC) and DG GROW) to strengthen the European economy and train students to be part of a high-quality workforce for the future. In its first years of operation, it received funds from Horizon 2020 and Horizon Europe and from membership fees. EIT Raw Materials is now the world's largest Research and Innovation (R & I) community with a focus on raw materials. The community emphasises collaboration between education and business and focuses on technical projects of commercial relevance with a high likelihood of success. EIT Raw Materials also manages the European Raw Materials Alliance (ERMA) and represents an important interface for the European Battery Alliance of the European Commission.
- **ERA-MIN** (ERA-NET Co-fund on Raw Materials) is a pan-European network of research funding organisations launched in 2011 which aims to support the EU raw materials Initiative, the European Innovation Partnership on Raw Materials (EIP RM), and further develop the raw materials sector in Europe through funding of transnational research and innovation activities. It has now reached its third incarnation. ERA-MIN3 (2020 – 2025, https://www.era-min.eu/about-era-min-3) sets out five key objectives in the area of non-fuel, non-food raw materials:

  1) Support and promotion of R & I cooperation in Europe;

  2) Reducing fragmentation of R & I funding;

  3) Providing a pan-European support network and financial resources to improve synergies coordination and collaboration;

  4) Improving the efficiency and impact of human and financial investment in R & I activities, and

  5) Improving the competitiveness and the environmental, health and safety performance of non-fuel, non-food raw materials operations.

1.2.2 National Geological Surveys

GSOs in Europe have been active for a long time. The Britisch Geological Survey (BGS) is the oldest national geological survey in the world dating back to 1835. For BGS and most other GSOs, the need for knowledge of mineral and other natural resources was a key goal in their formation. Over decades, an enormous amount of data and information has been obtained and archived. In recent times, more information has been gathered, new exploration models have been established and parts of or whole archives have been digitized and made available to the international community by individual GSOs, however at different speeds. Thus, GSOs collectively represent the key and most up to date archive of knowledge on geological resources in Europe.

The assessment of the geological resources is a core task for most GSOs. Mapping is an essential, recurring task that takes into account the current state of scientific and technical knowledge, for example, new geological models, improved and more diversified exploration methods, and changes in land use. Precise and state-of-the-art georeferenced base maps and thematic maps are the basis of strategic planning - be it in spatial planning, for physical infrastructure and other geostrategic issues of national and regional interest. While a company's decisions are also based on high-resolution spatially detailed information, other scales and comparable interdisciplinary information are important for political considerations. Thus, the chosen scale of a map depends on the task for which the map is to be used, but also on the available data density. For the development of national deposits, raw material deposits are usually mapped exclusively in the respective national territory. Deposits that are overlaid by political borders, on the other hand, are often insufficiently represented. Thematic geological maps together with accompanying data are hosted in national databases – often but not always in digital format. The structure of maps and databases depend to a large extent on the type of raw materials present (regional geology), the data density, the mapping methods, and the mining history of each individual country or region. However, it may also reflect regional or political priorities. While this makes good sense in a national, regional, or even local scale, it provides challenges when comparing the availability, accessibility, quality and quantities across borders and on a continental scale.

The collaboration in pan-European projects on raw materials became the catalyst for GSOs to harmonise national data to a pan European format. This resulted in a number of projects exploring ways to address the following challenges:

- Information type;
- the level of detail of information;
- the comparability of data;
- the accessibility of information.

In many of these projects, GSOs were acting as individual partners or associated partners through EuroGeoSurveys. While a hand-full of GSOs have been involved in most of the projects or even acted as lead in them, the majority of GSOs are fairly inexperienced in EU funded and co-funded projects. Learning from the more experienced surveys and increasing capabilities within the less knowledgeable surveys is a strong motivational factor within GeoERA Raw Materials and the embodiment of the European spirit. The selection below highlights the most relevant projects and networks that have influenced GeoERA Raw Materials:

ProMINE (Nano-particle products from new mineral resources in Europe, FP7-NMP funded project, 2009 - 2013; http://promine.gtk.fi) noted the EU's raw materials import dependency. PROMINE was an inspiration for GeoERA, as it developed the first pan-European GIS-based database containing the known and predicted metalliferous and non-metalliferous resources. These together identified the mineral resources (including secondary resources) of the EU and increased the number of potential mineral targets in Europe. ProMINE was the precursor for further pan European minerals databases (i.e., Minerals4EU/M4EU, MICA, MINTELL4EU), and for metallogenic maps and models which were further developed in the FRAME and MINDeSEA projects of GeoERA. PROMINE was led by the Geological Survey of Finland (GTK) with the GSOs of France (BRGM), Greece (IGME-GR), Spain (IGME-CSIC) and Portugal (LNEG) as partners along with several industry partners.

EuroGeoSource (EU Information and Policy Support System for Sustainable Supply of Europe with Energy and Mineral Resources, CIP-fund ed project, 2010 – 2013, http://www.eurogeosource.eu/). The main goal of the project was to develop an information and policy support system for the sustainable supply of energy and mineral resources in Europe. The system used Open Geospatial Consortium (OGC) specifications and provided INSPIRE compliant aggregated geographical information on geo-energy and mineral resources, covering 10 European countries. Eleven GSOs participated e.g. TNO (lead), RBINS, GEUS, EGT, MFGI, PGI, LNEG, GeoZS, GIR, including Estonia (EGT).

InGeoCLOUDS (Inspired GEOdata CLOUD Services, CIP funded project, 2012 – 2014; https://www.eurogeosurveys.org/projects/ingeoclouds/) was a feasibility study on the use of a cloud-based infrastructure in conjunction with the necessary services for seamless access to spatial data provided by the public sector. Particular attention was paid to the peculiarities of geological, geophysical and other geoscientific information, such as the size of the available dataset, the existing metadata and the current availability of associated services. As GSO´s BGRM, GeoZS, GEUS and H.S.G.M.E. were involved.

Minerals4EU (Minerals Intelligence Network for Europe, FP7-NMP funded project, 2013 – 2015; www.minerals4eu.eu) was designed to meet the recommendations of the Raw Materials Initiative. A minerals intelligence network with a sustainable operating service (the M4EU database) was developed providing an overview of European raw materials and a European Minerals Yearbook. The database was INSPIRE compliant and enabled data sharing in a harmonized way. It brought 32 partners (all GSOs) from 26 countries together.

MICA (Mineral Intelligence Capacity Analysis, Horizon 2020 funded project, 2015 – 2018; www.mica-project.eu) continued the efforts to collect, collate, and store information on primary and secondary raw materials, and make data accessible in the most useful way in order to correspond to stakeholder needs. The MICA project brought together a consortium of 15 European GSOs and other partners including the Joint Research Centre (JRC) in Ispra, Italy.

RESEERVE (Mineral potential of the ESEE region, EIT RM funded project, 2018 – 2021, https://reseerve.eu/) mapped the mineral sources of the six ESEE countries – Albania, Bosnia and Herzegovina, Croatia, Serbia, Montenegro and North Macedonia establishing the West Balkan Mineral Register for primary and secondary mineral resources. The data is also shared with Minerals4EU. The eight contributing GSO were led by GeoZS.

EMODnet-Geology is one of seven thematic data portals of the European Marine Observation and Data Network (EMODnet) to highlight and strengthen blue growth in Europe. EMODnet-Geology brings together harmonized offshore data, including seabed geology, seabed substrates, coastal behaviour, geological events and probabilities, submerged landscapes and marine minerals. Existing data products based on the EMODnet-Geology I, II, III, and IV projects are consolidated at a higher resolution and integrated with more recent additional data. The European Commission's Directorate General for Maritime Affairs and Fisheries (DG MARE) makes use of this trustworthy and reliable operational service which is accessible via https://emodnet.ec.europa.eu. The integration of EMODnet-Geology data into the general 'europa.eu' domain is an important recognition of the quality of the data and reflects the long-term commitment of DG MARE to the system. The GSO´s are the key drivers and data providers among the 31 partners and 9 subcontractors. EMODnet is hosted by GEUS.

GeoSeas (FP7 funded project 2009 – 2013; https://www.geo-seas.eu/) was a cornerstone of the EMODnet Geological data infrastructure and benefitted from national programmes and work conducted under UNCLOS. The 28 national GSO´s were among the key drivers and data providers on marine minerals and related topics. (GTK, BGS, SGU, NGU, GEUS (incl. the Faroe islands), EGT, LVGMC, LGT, PGI-NRI, BGR, TNO, GSB, BRGM, GSI, IGME-CSIC, LNEG, ISPRA, GeoZS, HGI-CGS, AGS, H.S.G.M.E., GIR, GSD, CSD, VSEGEI, BGS / Bulgaria, ÍSOR, and GSM)

MAP (Mineral Resource Assessment Platform, EIT RM funded project, 2018 – 2021; https://eitrawmaterials.eu/project/map/) was one of the few projects that produced a new method and software for the quantitative assessment of undiscovered mineral resources focussing on the Nordic countries, Germany and the Arctic deep ocean floor. In the marine research domain, the raw materials related funding programmes supported projects aimed at developing a better understanding of the marine ecosystem (e.g. MIDAS, iAtlantic, SCAN-Deep) and on those projects

focussing on technical aspects such as reliable environmental developments for the extraction of raw materials under extreme conditions (e.g. BLUE MINING, BLUE Nodules). NGU, GTK, SGU and ÍSOR were project partner.

POLINARES (POLicy for Natural RESouces, FP7-SSH funded project, 2010 – 2012, https://cordis.europa.eu/project/id/244516/de) looked at political, societal, and trade aspects related to the global supply and demand of raw materials from a European perspective. Scenarios and forecasts underpinned the understanding of what can be considered as critical to Europe's economy and forms a basis of the Criticality Studies of the European Commission. BGR was the only GSO partnering.

EURare (Development of a sustainable exploitation scheme for Europe's Rare Earth ore deposits, FP7-NMP funded, 2013 – 2017, www.eurare.org) established a harmonised and coherent overview of the occurrence of rare earth elements in Europe with the purpose of setting the basis for the development of a sustainable European REE industry. EURare created an online open access database combining geographical, mineralogical and technological data, 'Integrated Knowledge Management System' (IKMS, http://EURARE.brgm-rec.fr/download/dataset). Seven GSO´s were partners in this project (SGU, GEUS, BGS, GTK, BRGM, H.S.G.M.E. and NGU).

SCRREEN (Solutions for Critical Raw Materials – a European Expert Network, Horizon 2020 funded project, 2016 – 2019, www.scrreen.eu) aimed to bring together European initiatives, associations, clusters, and projects working on critical raw materials into a sustainable expert network. The network included stakeholders from public authorities, academia and civil society. The network contributed to improving the European CRM strategy and continues in SCRREEN2 (2020 – 2023) that covers all raw materials. The GSO´s are contributing through its Mineral Expert Group (MREG) and individually.

ORAMA (Optimising data collection for Primary and Secondary raw materials, Horizon 2020 funded, 2017 – 2019, www.orama-h2020.eu) developed the optimisation of data collection further by addressing specific challenges related to data availability, geographical coverage, accessibility, standardization, harmonization, interoperability, quality, and thematic coverage. The ORAMA project provided initial guidance documentation to apply the United Nations Framework Classification for Resources (UNFC) and recommends the establishment of more structured and continuous funding for establishing and maintaining a European data infrastructure for tracking both primary and secondary raw materials. Led by GTK among others eight GSO´s (BRGM, GeoZS, GEUS, ISPRA, MBFS, BGS, and NGU) joint forces.

ProSUM (Prospecting Secondary Raw Materials in the Urban mine and Mining wastes, Horizon 2020 funded project, 2015 – 2017, www.prosumproject.eu) delivered the first Urban Mine Knowledge Data Platform with information on secondary raw materials. The platform was linked to M4EU. Out of 17 partners five are GSO´s (BRGM, CGS, GEUS, GeoZS, SGU, EuroGeoSurveys (with HGI-CGS, GSD, H.S.G.M.E., GSI, TNO, NGU, PGI-NRI, LNEG, IGME-CSIC and GEOINFORM as linked third parties)).

1.3 Objects and Impacts

GeoERA Raw Materials supports efforts to enhance the responsible sourcing of mineral raw materials from European deposits to strengthen Europeans raw material resilience. Knowing Europe's raw materials potential and providing coherent and reliable data are key, for researchers as well as for decision makers. Hence, the objectives of GeoERA Raw Materials are predefined by the overarching aim to support EU raw materials policy. They range from a) extending, deepening and upgrading the quality of the pan-European primary and secondary continental and marine resources inventory; b) Updating contributions and augmenting the coverage of the Annual Minerals Yearbook; c) Performing pilot studies supporting exploration and development of mineral raw materials; to d) Implementation of innovative and efficient approaches throughout the mineral raw materials value chain for an enhanced management.

Recognising the value of reliable data, GSOs stepped into the gap left when EU funding ended at the completion of projects. This helped with the sustainability of established databases and assisted with keeping systems up-to-date with developments in information technology.

The project One Geology Europe (1G-E) was the pioneer project to which more than 20 GSO´s contributed to provide geological spatial data held by the Geological Surveys of Europe that are more easily discoverable, accessible and shareable. 1G-E made a significant contribution to the progress of INSPIRE – i.e. develop systems and protocols to better enable the discovery, viewing, downloading and sharing of core European spatial geological data. Since the project One Geology Europe (1G-E) the benefits of this collaborative effort are obvious. The success for 1G-E motivated to expand the scope and formed the basis of the European Geological Data Infrastructure (EGDI), launched by EuroGeoSurveys in 2016. Under the umbrella of EGDI, data is made available for scientists and citizens alike.

EGDI (www.europe-geology.eu) updates and enhances data owned by the EuroGeoSurveys community. EGDI provides access to several Pan-European and national data sets and geological services derived from harmonization projects, the latest being GeoERA, carried out by the GSOs of Europe.

Take away message 1

The development and continuation of a permanent digital infrastructure is vitally important for evidence based decision making.

EGDI provides the central data infrastructure

1.4 GeoERA Raw Materials scientific projects

Mineral Intelligence for Europe (MINTELL4EU) MINTELL4EU built on the work described above in several previous or parallel projects. MINTELL4EU has continued the effort to collect data on raw materials within Europe and presents them in a harmonized and INSPIRE compliant way. The spatial coverage has been increased as more countries contribute to the MIN4EU database, developed from M4EU, combining harmonized data on mineral occurrences and mines for many commodities (Minerals Inventory) with aggregated data on production, trade, reserves and resources (the electronic Minerals Yearbook). In addition, the UNFC was tested for several national cases and recommendations have been developed based on this trial. Finally, a map and descriptions of historic mines with tourist features or potential was developed, covering almost all of Europe.

Seabed Mineral Deposits in European Seas: Metallogeny and Geological Potential for Strategic and Critical Raw Materials (MINDeSEA) The MINDeSEA project was funding a transnational cooperative network of 12 GSOs and Marine Institutes, for the investigation of and exploration for seafloor mineral deposits in European seas. MINDeSEA produced maps, datasets, genetic models and case studies for the European Commission, stakeholders and Society. These are based on detailed studies and compile data on geology, geochemistry, mineralogy, environmental and regulatory issues for hydrothermal mineralization, polymetallic nodules, ferromanganese crusts, phosphorites and marine placer deposits. Raw materials covered include cobalt (Co), lithium (Li), tellurium (Te), nickel (Ni), REE, manganese (Mn), copper (Cu), and other strategic and critical metals. These were investigated and mapped in several seabed mineral deposit types under European seas, with a view to identifying alternative sources to the land-based mined deposits. MINDeSEA metallogenic studies have identifying areas for sustainable resourcing and providing information to support decision-making on the management of marine minerals and in support of Marine Spatial Planning.

Forecasting and Assessing Europe's Strategic Raw Materials Needs (FRAME) FRAME FRAME built on previous and current pan-European and national databases. FRAME increased strategic and CRM knowledge through a compilation of metallogenic maps for critical raw materials in Europe. These cover related metal associations and mineral potential both on land and offshore. Secondary resources, in terms of historical mining wastes and potential by-products were also considered. The mineral resources targeted extend beyond the current EU CRM list and include minerals and metals (e.g. Li, tantalum (Ta), and niobium (Nb)) that are strategic for the European downstream industry in the mid to long-term. One of the more innovative actions of FRAME was the production, through predictability studies, maps of areas of higher mineral potential. The core objectives were:

- To identify conditions and processes involved in the formation of strategic and 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;
- Display and distribute map and descriptions on the Information Platform, and
- Highlight mineral resources criticality to high-tech and downstream sectors.

European Ornamental Stone Resources (EuroLithos) EuroLithos seeked to shed light on yet another mineral resource that has been used for millennia and will be for centuries to come: ornamental stone. Europe's geology displays a rich diversity of stone resources that have left a significant impact on the common architecture and cultural heritage of Europe. In addition, these industries sustain a large number of jobs across the continent. In recent years, the sustainable qualities of ornamental stone, as a building material, have gained renewed attention, being more durable and climate friendly than concrete and other synthetic materials. EuroLithos had three main objectives:

- Develop harmonized map services for the most important European ornamental stone resources;
- Provide an 'ID-card' for such resources, and
- Provide guidelines on best practices regarding the sustainable management of those resources.

The project has created databases and maps for the 13 participating countries. The templates can be used to grow the database both by partner countries, and by including other countries.

2 Europe's raw material potential: the first component of an improved raw materials resilient value chain

This chapter will provide background information on the EU policies that triggered the GeoERA Raw Materials objectives. It focuses on the procedures for obtaining new data and information onshore and offshore. Background information, important developments and results on the raw materials under consideration are briefly presented and a short outlook on possible future joint projects is given. However, the individual project results, the methods and procedures developed cannot be dealt with in more detail in this chapter. In this respect, reference is made to the project results and the peer-reviewed publications.

Chapter 2 is thus dedicated to the scientific projects FRAME, MINDeSEA and EuroLithos. Chapter 3 is mainly devoted to MINTELL4EU with its focus on data provision.

2.1 Strategic and Critical Raw Materials

The concept of strategic raw materials dates back to the early 20th century and used in the context of national security and defence. It led to the US Strategic and Critical Stock Piling Act of 1939 (Andersson, 2010). The term is generally defined as materials essential to military, industrial, or civilian needs in times of national emergency (Haglund, 1984). These days, raw materials considered strategic given the current rates of consumption and emerging value chains, are likely to become scarcer and have a future supply risk associated with them. In the automotive sector for instance nickel (Ni), lithium (Li) and cobalt (Co) used in batteries, neodymium (Nd) and dysprosium (Dy) in permanent magnets, terbium (Tb) in lighting and fuel injectors, antimony (Sb), bismuth (Bi) and boron (B) for steel alloys and paintings, gold (Au) and silver (Ag) for electronics, indium (In) for screens and tellurium (Te) for steel alloys photovoltaic solar cells and electronics considered to be the most important chemical elements (Ortego et al., 2020). With the increased sales of electric and hybrid vehicles in China, Europe, and the U.S. for each of the last 10 years (IEA, 2021) even a base metal such as copper (Cu) might be considered strategic. Electric vehicles use more than double the copper of an internal combustion engine automobile, and in November 2021, a 7.5 % increase of e-vehicles registrations was reported in Europe, from 3.5 % or 550,000 units in 2019 to 11 % or 1,325,000 units in 2020 of total new car registrations (EEA, 2021). In addition, the metal is also used heavily in EV infrastructure, smart buildings.

Factors such as trade patterns, producer and distributer policies, population growth, lifestyle and geopolitical considerations triggered actions to lower the increased vulnerability of Europe's economy, see Chapter 1. It stimulated governments, companies, think tanks and many more to assess and evaluate the raw material value chain supply risks from different perspectives and varying purpose led to the concept of Critical Raw Materials (CRM) and to develop related measures (Erdmann and Graedel, 2011; Jin et al., 2016; Løviket al., 2018; Ferro and Bonollo, 2019; Schrijvers et al., 2020). The economic and technical dependency on a certain material, as well as the probability of supply disruptions, for a defined stakeholder group within a certain time frame are evaluated to assess the criticality (Schrijvers et al., 2020). For the European Union (EU), CRM are those which display a particularly high risk of supply shortage in the next 10 years, and which are economically and strategically important for European industry and associated with high import dependency from third countries (European Commission, without date). The supply risk is related to too few producers either at the country level or at the company level, or at the primary extraction stage. In addition, low economic or political stability of some key suppliers might increase distortion in the market. This risk is compounded by low substitutability, low recycling rates, and the lack of sufficient technological alternatives (European Commission, 2011). The two main parameters for determining criticality are economic importance (EI) and supply risk (SR). CRM are determined on the basis of which raw materials reach or exceed the thresholds set for both parameters (European Commission, 2017b). Hence, some of the strategic raw materials considered are also considered as CRM.

The European Commission has been concerned with CRM since 2008 when the Raw Materials Initiative (European Commission, 2008) was launched and published the first CRM list in 2011 at request of the European Parliament, calling for periodical updates ever since due to the developments in defining parameters of criticality. Since then, the EC has published revised and updated lists in 2014, 2017, and 2020. The European Commission consulted the RMSG to form an ad-hoc Working Group on Critical Raw Materials (WG-CRM) to provide expert knowledge and data. The Working Group included several National Geological Surveys and the Chair of the MREG of EuroGeoSurveys. With the publication of the third CRM list the Joint Research Centre (JRC) in Ispra has been assigned the task of monitoring CRM and to preparing the regular updates of the CRM-list. However, as details on CRM are rarely a matter of official statistics and as data are often heterogeneous or even lacking, the JRC and EuroGeoSurveys have signed a Memorandum of Understanding (MoU) to exchange expertise and data to support the EU in meeting the challenges of providing reliable data. Moreover, the SCRREEN2 (2020 – 2023) network set-up by the European Commission to ensure expert input to the criticality assessments includes both MREG and individual GSOs staff members.

In summary, strategic and CRM are crucial for key technologies required to meet societal goals and political targets. Currently, the most important technologies are permanent magnets and rechargeable batteries used in green energy, medical and defence devices, pharmaceuticals, micro-electronics, and other advanced products and services (JRC, 2020a; European Commission, 2020e). Goals and targets as set out by European Commission communication 'Fit for 55' increases the demand on critical and strategic raw material (European Commission, 2021b) which will be supported by trade measures and the setting of global standards. This crucial importance of strategic and critical raw materials has led to very specific actions within the EU.

2.1.1 Raw materials for the energy and digital transformation

> *"Raw materials have moved into the political spotlight because of their importance for the twin green and digital transition and geopolitical developments."*
>
> (*European Commission 2021c).*

A joint committee of the American Physical Society and Materials Research Society assembled in 2009 to investigate the material resources available to support emerging energy technologies coined the term 'energy-critical elements' (APS and MRS, 2011). The raw materials requirements for the energy sector range from energy production and to energy savings and storage (Vidal, 2018). Likewise, the general concept of CRM what's considered to be an energy-critical element (ECE) is neither universal nor constant but triggered by societal needs.

Confronted with climate change and the COVID-19 pandemic, mining and related industries are undergoing unprecedented change. Never has the pressure for sustainable production and resilient supply chains been stronger and never has it been more important to understand, define and document the mineral potential of Europe. The European Green Deal and the new EU Industrial Strategy acknowledge that access to resources is a strategic security issue for ensuring the success of the green and digital transformations (European Commission, 2019a; 2020e; 2021a). The European Green Deal aims to reach net-zero carbon emissions by 2050. To achieve this, the EU is endeavouring to build a digital and net-zero economy through its Action Plan on CRM. This plan aims to ensure access to minerals for key industrial ecosystems such as renewable energy, e-mobility, and digital innovation (European Commission, 2020b). Forecast studies and research on materials for key enabling technologies underpin the strategies (European Commission, 2020e; JRC, 2020). Alliances such as the European Battery Alliance for battery storage and the European Solar Initiative for solar photovoltaics have been plotted in order to realise decarbonising projects in a targeted and speedy manner through industrial leadership

organised in EIT InnoEnergy (https://www.innoenergy.com) and base on the Strategic Action Plan on Batteries (European Commission, 2018a).

The pandemic has highlighted the need of building integrated, sustainable and transparent value chains, from mine to consumers. The World Economic Forum notes again in its Global Risk Report of 2022 that there are sudden shocks in the supply and demand of systemically important goods at the global level that put a strain on corporate, public and/or household budgets, including metals and minerals, and sees a worsening of the situation during the pandemic. In the course of the pandemic consumers faced delivery bottlenecks for common, everyday necessities (e.g. semiconductors as indispensable components in e.g. washing machines, refrigerators and automotive, and that delaying worldwide delivery of new (e-)vehicles and has caused short-time work for manufactures). To build a greener, digital and more resilient Europe, the EU is making available a long-term budget, coupled with NextGenerationEU the EU's temporary instrument designed to boost recovery from the pandemic through a commitment to multiannual budgeting which is the largest stimulus package financed by the EC. The Economic and Social Committee of the European Parliament (EESC) stressed during the Raw Materials Conference on 31 January 2022 that this finance packaged should also be used to boost sustainable domestic sourcing and invited ERMA to play an advisory role in identifying promising projects to make Europe economically more resilient through diversifying its supply chains and addressing the challenge of securing access to sustainable raw materials.

The EESC calls to widen the definition and the paradigm of critical raw materials. Raw materials that are an essential part of many supply value chains, and whose mining and extraction also produces critical raw materials as a by-product, should be recognised as having strategic importance (EESC, 2021). With the FRAME project, GeoERA Raw Materials response to this call already.

The work undertaken in FRAME and MINDeSEA, with particular incidence on the ECE, has benefitted from the collaboration of members of the MREG of EuroGeoSurveys. This collaboration has resulted in an additional 60 % increment in the previously available data on the ECE and the separation of the different types of graphite into amorphous and flaky graphite, which was not separated before FRAME (Figure 2.1). MINDeSEA produced the first pan-European maps of Co and Li based on ferromanganese deposits in polymetallic nodules and crusts on the seabed, showing the importance of these mineral deposits for other ECEs such as Te or rare earths (REE).

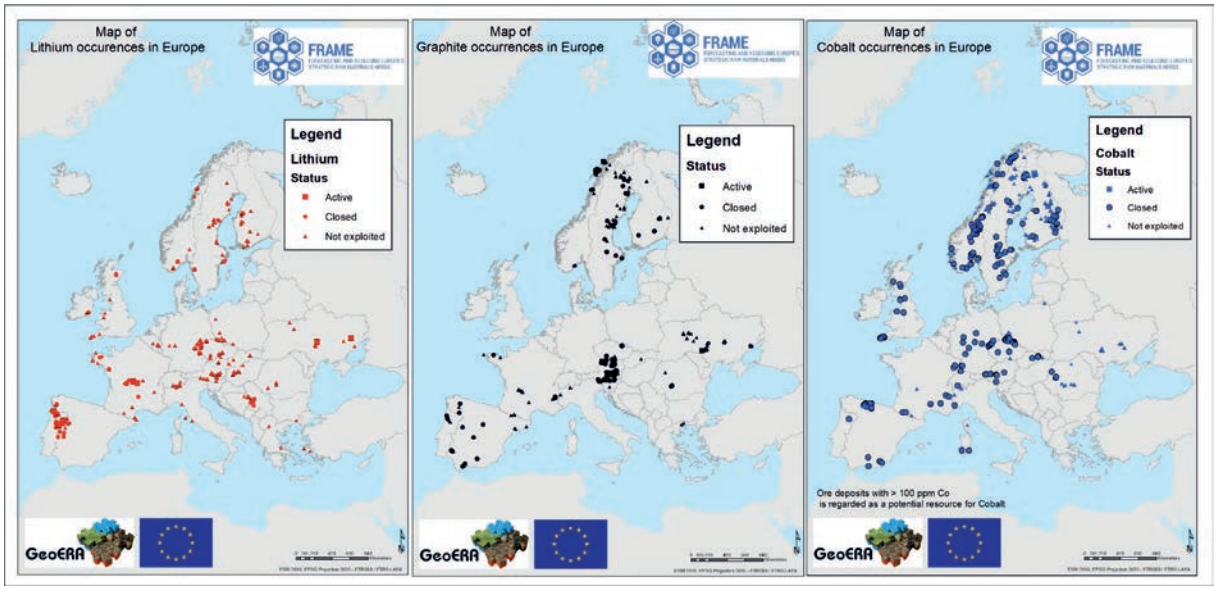

Figure 2.1: *Energy critical elements (Li, Co and natural graphite) mineral occurrence map. Compiled by the FRAME project.*

2.1.2 Unique ornamental stone resources

Ornamental stone (included in the wider term 'natural stone' and equivalent to the INSPIRE term 'dimension stone') is a mineral commodity group that is not critical nor has direct strategic importance but can play an important role in the green transition. The reason for this is simple: ornamental stone is a natural construction material, fashioned to craft useful construction elements. Stone is one of the non-organic construction materials that is sustainable through simple means. Most important is that ornamental stone is minimally processed, requires little energy input and has no or few emissions (Calkins, 2008). In addition, ornamental stone is a high-quality, durable material that is easy to recycle, and even if that is not possible, it is easily disposed of in a safe manner. The main challenges for ornamental stone production in the green transition are: 1) traditionally high waste ratio (research is needed so that the waste can be used as aggregate, industrial minerals or other purposes); 2) land use (and thus impact on land and eco-system services); and 3) transport (the larger the distance, the greater the impact). Regarding the latter, the transition will clearly favour the use of local resources where possible as "stone can be considered as a low impact BM (building material), if quarried locally, minimally processed and used appropriately" (Joseph and Tretsiakova-McNally, 2010).

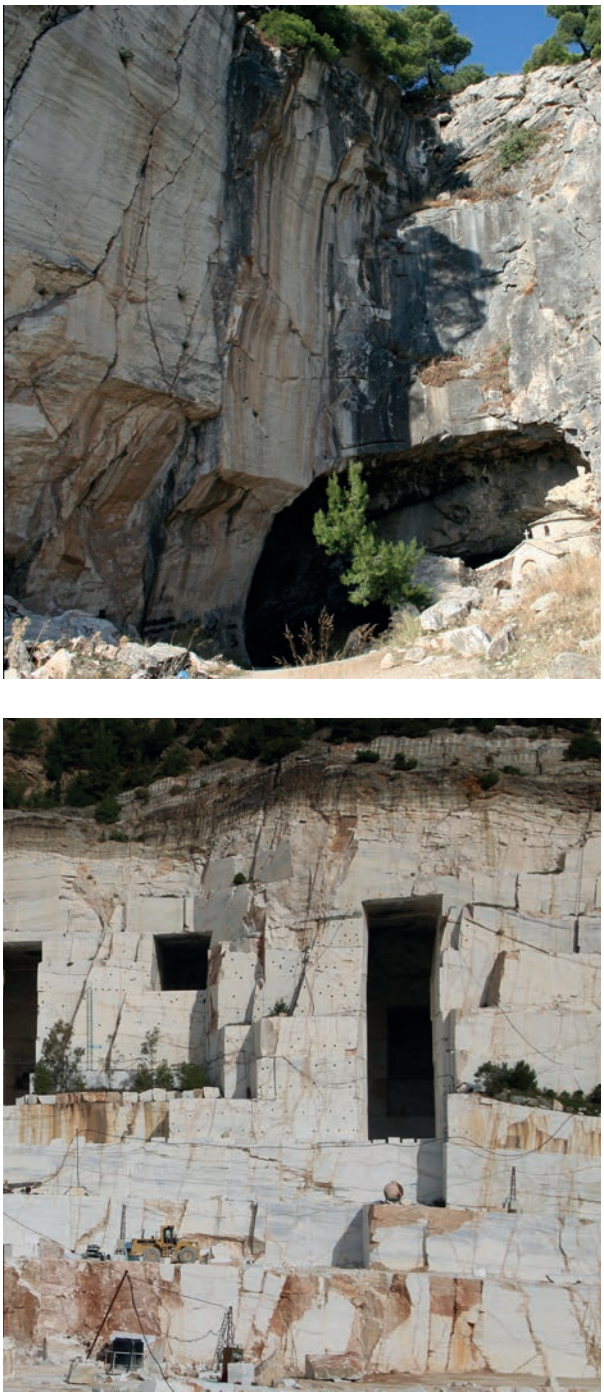

Figure 2.2: *Stone quarries past and present - 2500 years of mining the Pentelli marble in Greece. Above: quarry from Antiquity, below: modern quarry. Photo courtesy Tom Heldal, EuroLithos-project.*

Another indirect impact of the green transition is the social impact from mining and quarrying. The integration of environmental and social impact assessment should lead to the avoidance of "the cheapest there is" as the only criteria for the purchase of materials in the future, unless environmental and social criteria are also satisfied (Palumbo and Traverso, 2022). Clearly, such changes will also change the market conditions, and increase production costs even in low-cost societies. EuroLithos comes in timely by providing fact sheets and atlases and will continue that work.

The European stone industries should then face a future of competitive advantage, by being 'local', and by being familiar with strong environmental regulations and high standards of safe and ethical production. The concept of responsible sourcing and due diligence relies on resource efficiency, low emissions and socially acceptable production. Seen from a sustainability perspective, this should favour local or regional sources (Figure 2.2). Furthermore, the European Commission Due Diligence initiatives will probably affect the global ornamental stone market, in contributing to the harmonisation of production costs around the world (European Commission, 2020d). These aspects align with the requirements of cultural heritage, maintaining

authentic material use throughout the huge diversity of European architecture and the built environment constructed over millennia.

AHistorically, ornamental stone has been used both for structural and aesthetic purposes. Although in recent years it has been used almost exclusively for the latter, there are signs of new ideas for innovative structural use linked to low-emission buildings. Architectural agencies are developing applications where steel is replaced by stone, and there are examples where the replacement of concrete with stone proved both economical and more sustainable due to stone's extraordinary durability and wear resistance. Therefore, it is likely that European sources of ornamental stone will become more important in the years to come, as a sustainable and easy-recyclable construction material along with its heritage value. Some of those cultural treasures are documented and highlighted by EuroLithos.

2.1.3 Responsible sourcing

'Sustainability' covers more than carbon emissions, and 'responsible sourcing' more than conflict minerals. In addition to reducing environmental and ecological impacts, sustainability also includes social responsibility and human health (Brundtland Commission – UN, 1987). The green transition will lead to a growing number of regulations connected to responsible sourcing. One of those, known as the Conflict Minerals Regulation (Regulation (EU) 2017/821), came into force in 2021. This regulation sets standards that are introduced by, for example, the construction sector, underpining actions to ensure sustainability and responsibility.

The integration between environmental and social impact assessment (i.e. social criteria in the Ecolabel scheme; Franken and Kickler, 2017; Palumbo and Traverso, 2022) will lead to that "the cheapest there is" cannot be the only criteria for purchasing materials in the future, unless both environmental and social criteria are met. This may lead to a better competition ground for the European ornamental stone industries (see also section 2.1.2) and other domestic raw materials suppliers.

However, responsible sourcing requires action by all - producers and consumers – to ensure that the high ethical, social, environmental and labour standards to which the EU has committed are respected. Subject to high sustainability standards respected worldwide, the EU could also be competitive in the extractive industries, especially in the light of the EU's ethical concerns and the provision of a good work-life balance. Thus, responsible resource extraction could be the key to competitive extraction from domestic sources.

Currently, a broad acceptance for exploration and mining within Europe is lacking, which hampers necessary investments in research, exploration, mining and processing of Europe's raw materials potential.

Greenfields vs brownfields exploration

Greenfields exploration – Greenfields exploration relies on the predictive power of ore formation models to find mineral occurrences in previously unexplored areas or in areas where they are not yet known. Grassroot exploration is carried out to verify the basic conceptual idea of the location of a mineral occurrence. This is usually the field of GSO activities and involves e.g. aerial satellite surveys, geological and geophysical prospecting and ground surveys, and the definition of drill target areas. These basic exploration projects are the riskiest projects in the mining business. According to some statistics, only 1 in 5,000 to 1 in 10,000 basic exploration projects ever reach the production stage, but most form the basis for Advanced Exploration Projects with over well-defined mineral resources with reasonable prospects of becoming stand-alone mines or satellite mines. In the mine life cycle, these projects are generally between the pre-feasibility and feasibility stages.

Brownfields exploration - Exploration near a known deposit or in the vicinity of an already operating mine, with significantly lower exploration risk. This is usually the area of activity of industry and entrepreneurs (junior companies).

2.2 Prospective regions of Europe

The global demand for strategic and critical raw materials, together with the diminishing quality and quantity of the land-based deposits being mined, requires us to look for new environments and regions to explore.

In 2021, the worldwide budget for nonferrous mineral exploration amounted to approx. 10 billion Euros (Garside, 2021). Back in 2011 – 2012 metal prices performed similarly as they did from mid-2020 to mid-2021 stimulating exploration investments 83 % higher than in 2021 (Murphy, 2021). S & P Global Market Intelligence analysts expect gold to maintain its status as the primary exploration target by a wide margin due to continued high prices in the metals market, and also expects above-average increases for copper and nickel as well as continued interest in lithium and cobalt exploration. Even though the global trend is to some extent mirrored in the EU, the total exploration budget spent for metal projects in the EU is significantly lower than in all other regions of the world (see Fig. 3.3. European Commission, 2021c). Moreover, for certain metals, e.g., gold, the frequency of new discoveries has fallen even with a significant increase in exploration budgets (Callaway and Ramsbottom, 2019).

It is recognised that mineral exploration is essential to ensure a stable and sustainable supply of raw materials in the future. Prior to the first step in the mining life cycle, exploration contributes to define areas of mineral potential, to the discovery of new deposits or to improve the knowledge about existing ones that could in time become new sources of metals/raw materials. Mineral exploration is therefore an indispensable step in the EU's strategy for securing raw material supply (European Commission, 2018b; European Commission, 2021c).

The attractiveness of Europe's 'brownfields' prospective areas remains high and are defined (e.g. Figs. 3.1, 3.2 European Commission, 2021c) and relatively well known. However, the issue is what to look for, and where, when moving into 'greenfield' areas. These areas of higher economic risk require systematic, cohesive, multitask and efficient exploration programmes to increase the chances of new lon-shore mineral discoveries; so far the area that contributes the largest quantity of metallic minerals for industry. Europe has invested in this area by financing several projects that aim at minerals:

- Collecting and homogenising mineral inventory data (e.g. EuroGeoSource, ProMine, ORAMA, Minerals4EU, MINTELL4EU);
- Reanalyse mineral data in light of new technology and improved IT power (e.g. ProMine, SCRREEN1 and 2, EURare, FRAME, MINDeSEA, EuroLithos);
- Securing supply with balanced land use planning (e.g. Minatura 2000, Minland);
- Mineral intelligence capacity analysis (e.g. MICA);
- Education (e.g., Intermin) and promoting fora for experts to discuss current EU issues (e.g. ERECON, CRM list, ERMA, amongst others).

The pressure on land-based mineral deposits increases daily and hence, society's well-being and future prosperity depends on mineral deposits mined both on land and under the sea, the latter including mining from the depths of the ocean. European seas cover about 15 million square kilometers in the Arctic and Atlantic oceans, the Mediterranean, Baltic, and Black seas, which vary from shallow waters up to 6000 m water depth. This underexplored area is addressed by MINDeSEA (Figure 2.3).

Covering more than 70 % of the planet, seas and oceans represent a potentially promising, new frontier in the exploration for mineral resources. Spanning a large diversity of environments and resource types, including high and low temperature hydrothermal deposits (seafloor massive sulphides (SMS), sedimentary exhalative (SEDEX), phosphorites, cobalt-rich ferromanganese crusts, and manganese nodules, deep-sea deposits are particularly attractive for their polymetallic nature with potentially high contents of rare and critical metals. In addition, shallow-water resources, like marine placer deposits, represent another potential source for many

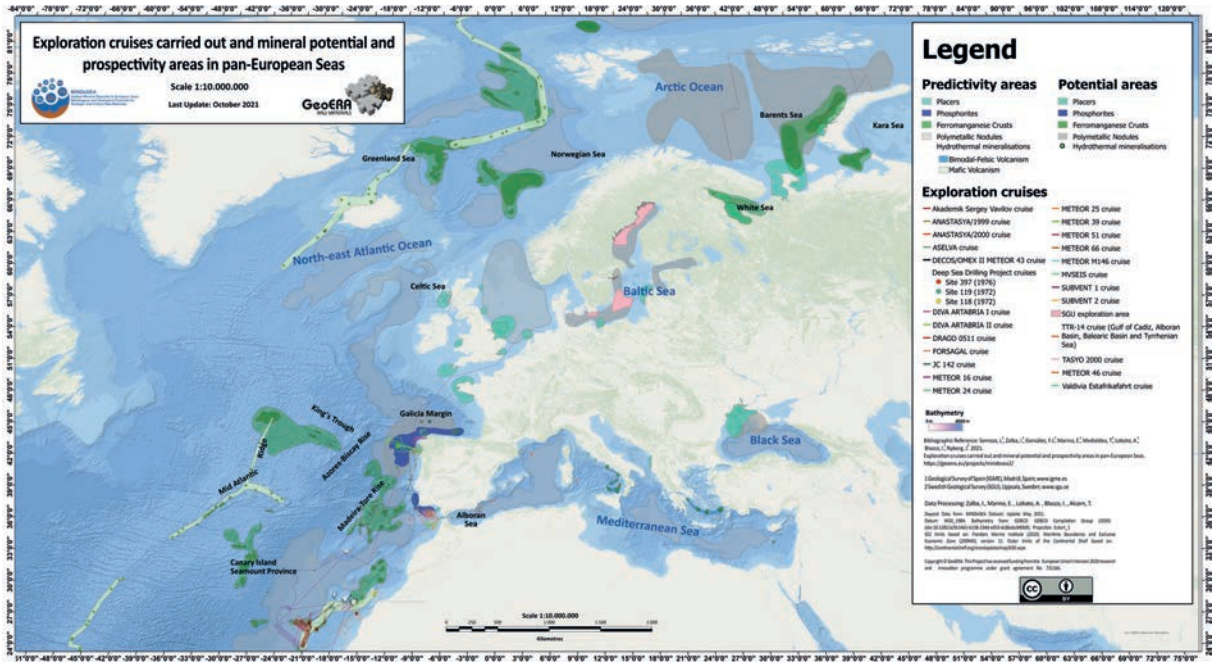

Figure 2.3: Exploration cruises carried out and mineral potential and prospectivity areas in pan-European seas (Somoza et al., 2021); source MINDeSEA project.

industrial materials, critical metals, and gemstones. Seabed mineral deposits host the largest resources on Earth for some critical metals like cobalt, tellurium, manganese, and the rare earth elements (Hein et al., 2013; 2020).

One such environment is beneath the sea. Thirty contractors have entered into 15-year contracts with the International Seabed Authority (ISA) aimed at exploring for manganese nodules, polymetallic sulphides, and cobalt-rich ferromanganese crusts in and on the seabed of the deep Atlantic, Pacific, and Indian oceans (ISA, 2022). The ISA is made up of 167 Member States, inter-governmental organisations (including the European Union), and non-governmental organisations. At the moment it is completing the drafting of normative regulations that will permit states, organizations, or companies to develop and work minerals in areas beyond national jurisdictions.

Several projects have been promoted by the European Union, within the Raw Materials Initiative, in order to locate and evaluate strategic and critical minerals. Recently, EU research programmes are funding projects to increase knowledge about seabed minerals, marine minerals exploration, extraction technologies, and environmental issues. These projects, along with national and international programmes related to all aspects of seabed minerals, will play vital roles in the emerging 'Blue Economy'. Extracting minerals from the deep sea represents an enormous scientific and technological challenge for society. Oceans can play a key role not only in the mitigation of climate change (Levin and Le Bris, 2015), but also in the sustainable use of mineral resources (World Bank, 2017). These issues include science-based decision-making between competing uses such as fisheries, offshore wind energy, the conservation of aquatic environments and ecosystems, positioning of infrastructure (pipelines, energy cables, telecommunications), shipping, leisure activities, and mining. All need to be considered in the context of maritime spatial planning. Considerable improvement in our knowledge of the oceans and seas is necessary to develop a sustainable 'Blue Economy', and in order to obtain a social license (Kelly et al., 2017; Koschinsky et al., 2018).

2.3 Results and outlook on future work

GeoERA research confirms the significant potential for mineral resources in Europe. In addition, it highlights that this potential is not confined to onshore areas but also encompasses marine areas. Enhancing the knowledge of onshore and offshore mineral potential in Europe is a strategic goal that should go beyond commodities such as phosphate (P) or cobalt. Many of the aspects highlighted in the FRAME and MINDeSEA projects bring to light new and important minerals intelligence data. These are derived from the use of different methodologies to highlight the mineral potential in Europe and show where knowledge gaps exist and how these can be mitigated.

The objectives of the GeoERA Raw Materials projects have been achieved and surpassed. GeoERA projects have identified several areas which should be given priority, namely:

- **Data and maps** require regular up-dates. Data were provided by many organizations, some of whom were not partners of GeoERA. Some countries or organisations do not have a national database, but delivered tailor made data to GeoERA projects. Thus, the data and maps are static, reflecting a moment in time, and cannot be expected to be updated regularly. Sustainability and improvement of these data and associated maps would require that all contributors ensure their data would be part of their national database and that they are kept up to date so that they regularly can be automatically collected ('harvested') to MIN4EU, see also section 3.1. This will ensure that data are always up to date in the future and ready for use for any purposes, and that the associated interactive maps at EGDI are similarly always representing updated data
- The general lack **of up-to-date pan-European information** on resources/reserves is an outstanding issue hindering the assessment Europe's CRM potential. Such information is crucial to define new areas of interest as shown, for example, in REE recovery from apatite exploitation in the case of phosphates. Also mapping, sampling and geochemical analysis of CRM content at historic mine sites is urgently required on a continental scale to assess Europe's raw material potential from these sites. While some detailed data are available there is still an enormous amount of work required to cover the entire continent.
- **Data collected** for continental Europe and for the European seabed area allows the classification of Europe's mineral deposits according to genetic types. If resource data exists, then this may be classified using the United Framework Classification for Resource (UNFC) system. However, much more data will be necessary to obtain detailed information on each submarine mineral deposit as a basis for grade and tonnage calculations or even estimations. Further application of the UNFC requires national and international policy frameworks to ensure that all relevant data for the UNFC are available. Extensive training is needed to ensure a common understanding of the UNFC system to ensure that the results are transparent, comparable, and reliable, see also section 3.1.4.
- **Systematic collection** of mine status, grade and tonnage information, and more detailed geological information such as: age, mineralogy, geochemistry, petrology, metamorphism, geophysics, detailed geological setting and petrogenetic details is required. The MIN4EU database is structured to store these data types, but not all contribute with such details. The geological data can be used to improve predictive modelling that are crucial to validate exploration models and to attract investment.
- **The quality and quantity of input data** is critical to prospectivity mapping. Each data- or knowledge-driven method has its advantages and limitations and there is no single 'best' method. For whatever method(s) is chosen, sets of multidisciplinary, harmonized, and complet data are crucial in preparing favourability and prospectivity maps (see lithium favourability map, Figure 2.4 and cobalt-rich ferromanganese crust metallogenic map, Figure 2.5). Gathering harmonized data on mineral deposits is the first step at the European scale and continuing efforts to improve the harmonisation of data among data providers is essential.

- **Modelling Methodology:** Cell Based Association (CBA) is an innovative mineral favourability procedure that compares different attributes from different datasets. CBA adds to modern exploration methods by providing enhanced favourability maps (Bertrand et al., 2021; Bai et al., 2021). Those situations relate to input data quality (e.g. clustered points, mixed and scarce data, approximate location) or some assumptions that are considered unreasonable (e.g. map areas relevance, conditional independence). The principle of CBA consists in replacing polygons of geological units with a square cell grid (hence the 'cell-based'). Each cell contains a range of units (‚association') that are binary coded in terms of their presence (1) or absence (0) within study area (Tourliere; et al., 2015). It is this innovative and relatively unknown method that was used to generate the favourability maps generated in FRAME and MINDeSEA. These were derived from harmonised, stacked datasets that enable the identification of more permissive and prospective areas at the continental scale and reflect current geological data and knowledge. An important feature of the Li-Co-graphite mineral occurrence map is that it was developed using harmonised data (Figure 2.4). Identification and promotion of the **highest mineral potential of an area** by GSOs is a tool to improve effectiveness and efficiency of future investments in exploration. In these stages, data and future updates of knowledge on mineral systems at a regional scale, economic geology approaches, geochemical data, and airborne geophysics measurements need to be overlaid to produce prospectivity maps at regional and local scales to identify target areas with higher exploration potential. Ultimately, the assessment of any highlighted areas will consider knowledge and data updates addressing deposit scale exploration efforts including alteration, mineralogy, ground geophysics and detailed geochemical sampling. This holds also for historical deposit areas where detailed, thorough, quantitative studies are needed to assess the potential for mineralization, and identify new resources of critical elements. An additional benefit is that these data provide understanding and support for land and maritime special planning and competing land and sea uses.
- Comprehensive geochemical and mineralogical studies (geometallurgy) of ore minerals and associated CRM would enhance the knowledge on the deposits, how they formed, and could help identify methods for CRM recovery.

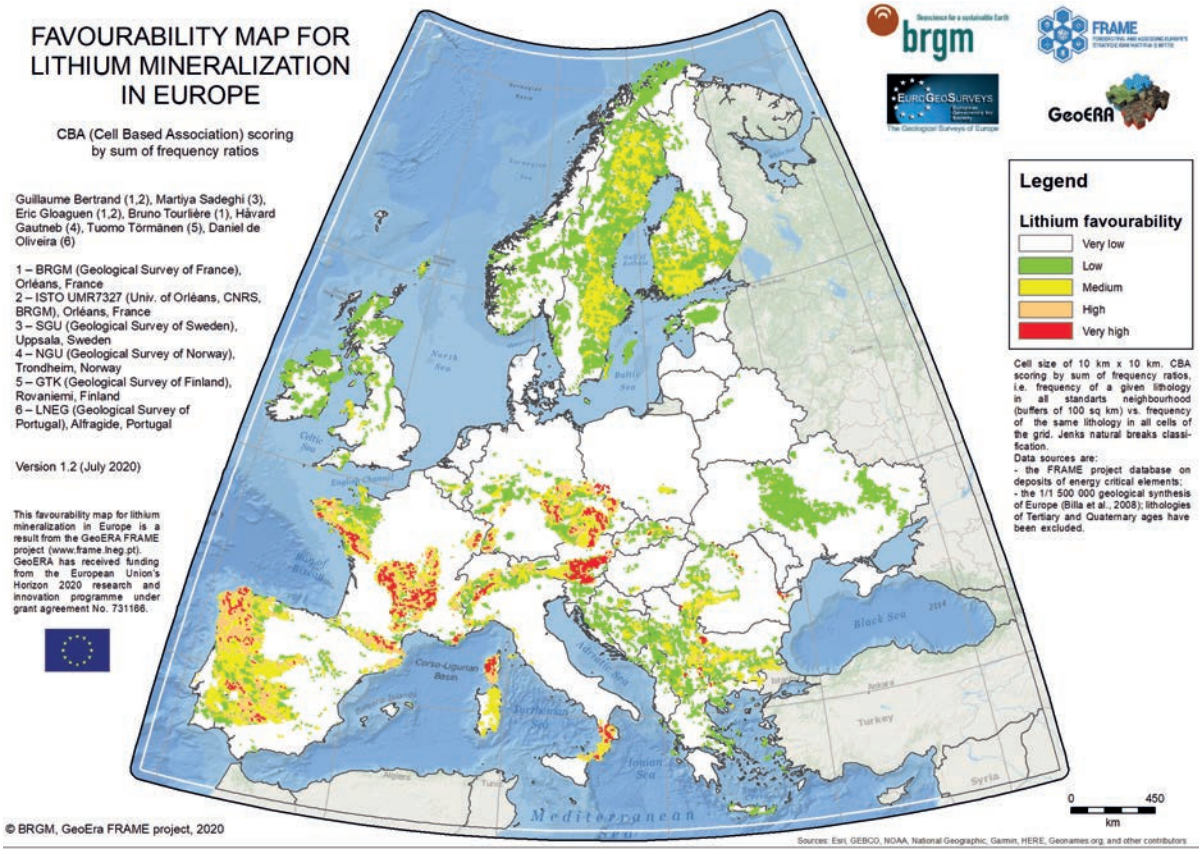

Figure 2.4: Lithium Favourability Map for Europe using the Cell Based Association Method; source FRAME project.

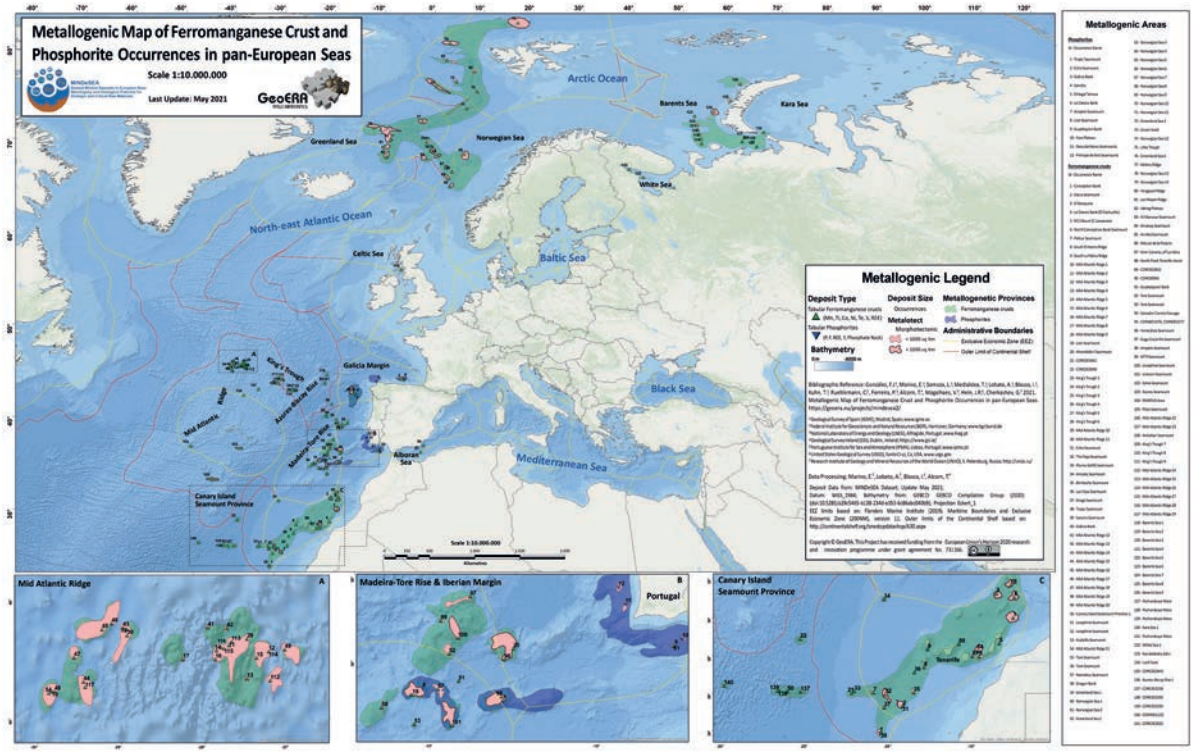

Figure 2.5: Metallogenic map of Co-rich ferromanganese crusts and phosphorites in pan-European seas (González et al., 2021a); source MINDeSEA project.

- From the results obtained in GeoERA RM, **in-depth metallogenic studies** should be considered in a number of areas. Examples include:

  The Larvik Plutonic Complex (Norway) hosts the Kodal deposit in which one of the most valuable ornamental stones in Europe (Larvikite) is produced. Further investigations, including detailed geophysical surveys, will help evaluate the potential for apatite resources (and REE) in the rest of this promising Complex. Systematic (even preliminary) assessment of the REE potential of the phosphate mineralization should be carried out during the exploration (or exploitation) phase of a deposit.

  Seamounts, submarine volcanoes and banks in the **Macaronesia sector** (Portugal and Spain) and the Arctic ridges (Norway, Denmark, Iceland) show a high potential for Fe-Mn crusts, which may be rich in energy-critical elements like Co and also Te, REE, and titanium (Ti) and Mn.

  The **Bohemian Cretaceous Basin** (Czech Republic) is an example where new information (e.g. concentrations of CRM) can lead to the discovery of new occurrences/ deposits not recorded previously. Even though the size/ morphology/ potential of the known phosphate deposit do not seem favourable for exploitation now, it could be in the future, considering, for instance, the rapid developments in the field of robotics in mining.

  Phosphorites on the seafloor of **Iberian continental shelves and slopes** along the western continental margins of Portugal and Spain are phosphate deposits which should be investigated further (Figure 2.6).

  The **Bothnian basin of Sweden** contains significant Li-Ta-(Nb) potential, featuring several clusters of LCT-pegmatite occurrences encompassing hundreds of individual dykes, which were discovered during the 1980s. Of the various pegmatite dykes (e.g. Järkvissle dykes) and fields present in this area, only a few have been subject to in-depth exploration and more work is needed to both characterize them and to meet the requirements of modern reporting standards.

  Seafloor polymetallic sulphides and metalliferous sediments precipitating from hot hydrothermal solutions and plumes are forming today in the **Azores Islands** (Portugal), **the Arctic** (Norway and Denmark) and t**he Mediterranean volcanic arcs** (Italy and Greece) (Figure 2.6).

Figure 2.6: *European seabed minerals. In the upper side, crosscut sections of phosphorites from Galicia Bank (NE Atlantic); below, submarine ROV image of sulphide-anhydrite chimneys from Moytirra hydrothermal field (Mid-Atlantic Ridge). Photo courtesy IGME-CSIC; source: MINDeSEA project.*

- There are a number of areas which have the potential to host **future projects**:

  Phosphate deposits – Despite the Lower Paleozoic sedimentary phosphorites constituting most of the phosphorites in Europe, testifying for the presence of a phosphogenic province within the Avalon and the Baltic Platforms, refined prospectivity mapping should be carried out in the most prospective mineralized areas, for example (i) the igneous complexes in Norway, which contains P mineralisation and hosts many different, less well-understood phosphate deposit types (Figure 2.7), and (ii) the area covering Belgium and Northern France, which is known for the abundance of phosphatic chalk. In cases of areas which host historical mining waste deposit of remarkable size detailed, comprehensive prospective studies are needed to assess the potential for mineralization in areas.

The MINDeSEA results show the potential of pan-European seas for critical metals. The exploration and mineral prospectivity maps show the areas that require further research and in addition highlight areas where there is little or no information (Figure 2.8).

- **Common analytical procedures and improved methods:** internally consistent geochemical data at European level can be achieved when preparation and analysis of samples follow the standard / guidance. This is illustrated by the example of P-mineralisation in Europe or for submarine ferromanganese deposits. This requires further work on reliable standards that include more efficiently prepared / obtained well-tested phosphate, nodule and crust standards to ensure the homogeneity of data, particularly for in-situ analyses and for the trace element content when whole rock analyses are performed.

  Comprehensive geochemical and mineralogical studies (geometallurgy) of ore minerals and associated CRM would enhance the knowledge on the deposits and how they formed and could help to identify methods for CRM recovery.

  The application of new or improved portable analytical techniques including LIBS and XRF should be tested in this context to expand the niobium (Nb)-tantalum (Ta) or other critical raw materials potential. Challenges for exploiting areas of potential including historic mine sites and especially mine waste, incorporates issues regarding legal aspects, responsibilities on regional and even municipal level, environmental issues and above all economic questions as nearly all CRM are minor components in deposits and thus their production may depend on the economic extraction of the main commodity (often base metals).

- **Strategic actions:** Hurdles keep cropping up in the raw materials value chain that hinder sustainable and responsible sourcing and impact social acceptance and operating licences in Europe. To identify these and to work on solutions ahead of policy driven R & I or CSA calls by the EC is a strategic aim of GeoERA and of FRAME, in particular. An example is the complex nature of so called 'conflict mineral', issues which require that the underlying factors of responsible sourcing are also considered and adequately addressed (see also 2.1.3). A narrow focus on only the supply chain and policies based exclusively on legal regulations to control the mineral trade can be blunt instruments that may create unintended effects which may seriously affect small-scale producers and artisanal miners. To avoid the exclusion of sustainable small-scale mining operations and to assist companies in complying with new rules, the Regulation (EU) 2017/821) provides for accompanying measures that are designed to counteract and mitigate unwanted effects. Such measures are also intended to ensure traceability, which involves supporting local artisanal miners and improving their working conditions. There has been much recent research on these issues, and many projects aim to support sustainable sourcing of raw materials from conflict areas. Despite this, the need for expanded and long-term European initiatives to assist in the improvement of the conditions of mineral production in the central African region cannot be emphasized enough and the issues represent significant challenges. Clearly, additional means and ways to improve both regional and local conditions must be harmonized and range from the larger-scale political level, down to concrete issues of social conditions, and health and safety at local mining sites.

  Imports from responsible, sustainable, conflict-free producers as per the EU Conflict Minerals Regulation (EU) 2017/821) will most likely be the main realistic option for European Ta and Nb sourcing in the near future, but due to the inherent supply-risks, it is necessary to identify new, viable primary and secondary European sources from which these metals can be obtained.

  The mineral endowment of Europe includes several deposit types, e.g. rare metal granite-pegmatite-aplites, alkaline igneous rocks and carbonatites where Nb and Ta are present (Figure Figure 2.9), but in all cases more detailed exploration work is needed to identify their full economic potential.

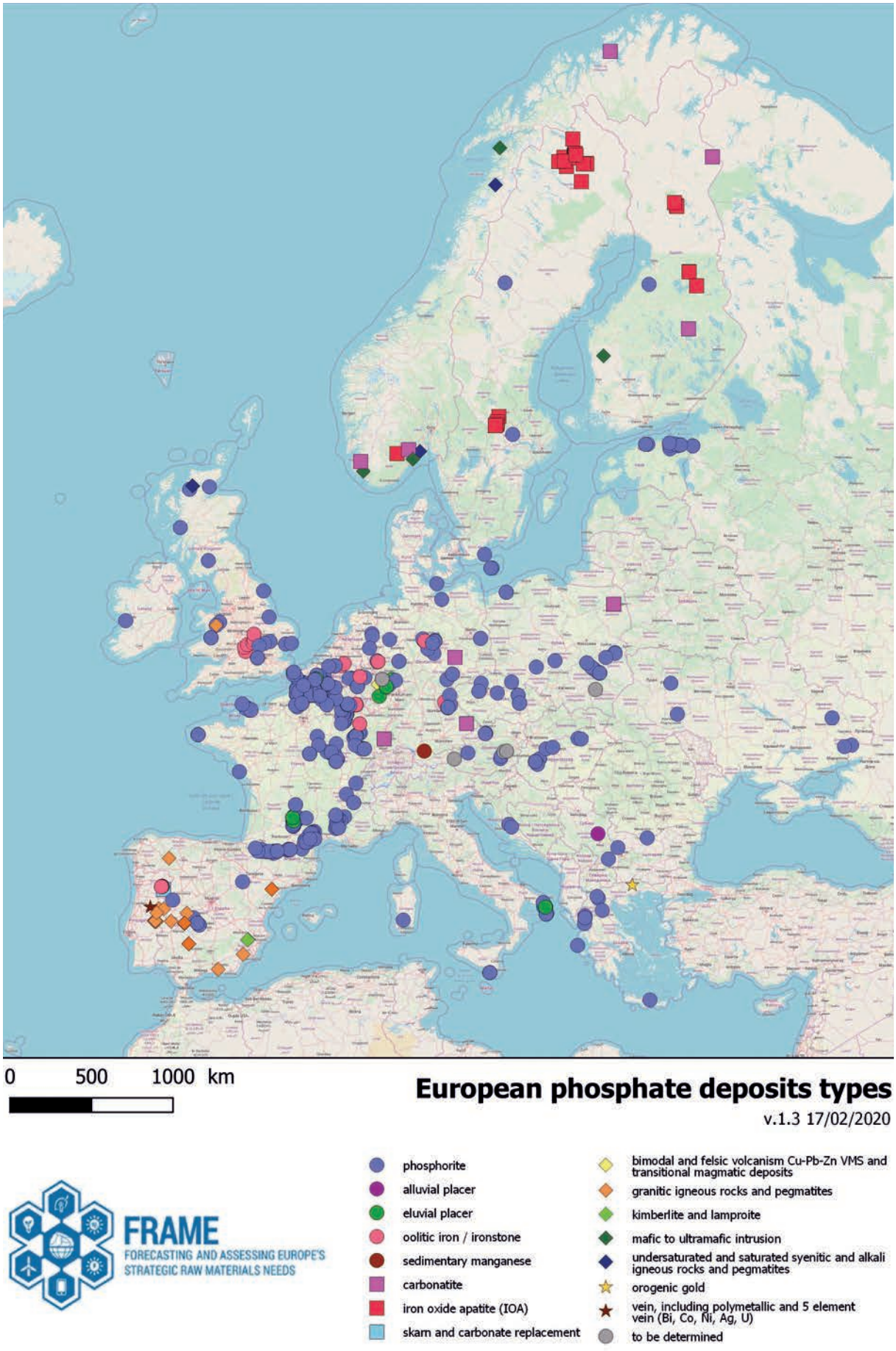

Figure 2.7: *Map illustrating the mineral deposit type of phosphate mineralisation's presented in the databases provided in the FRAME project; source FRAME project.*

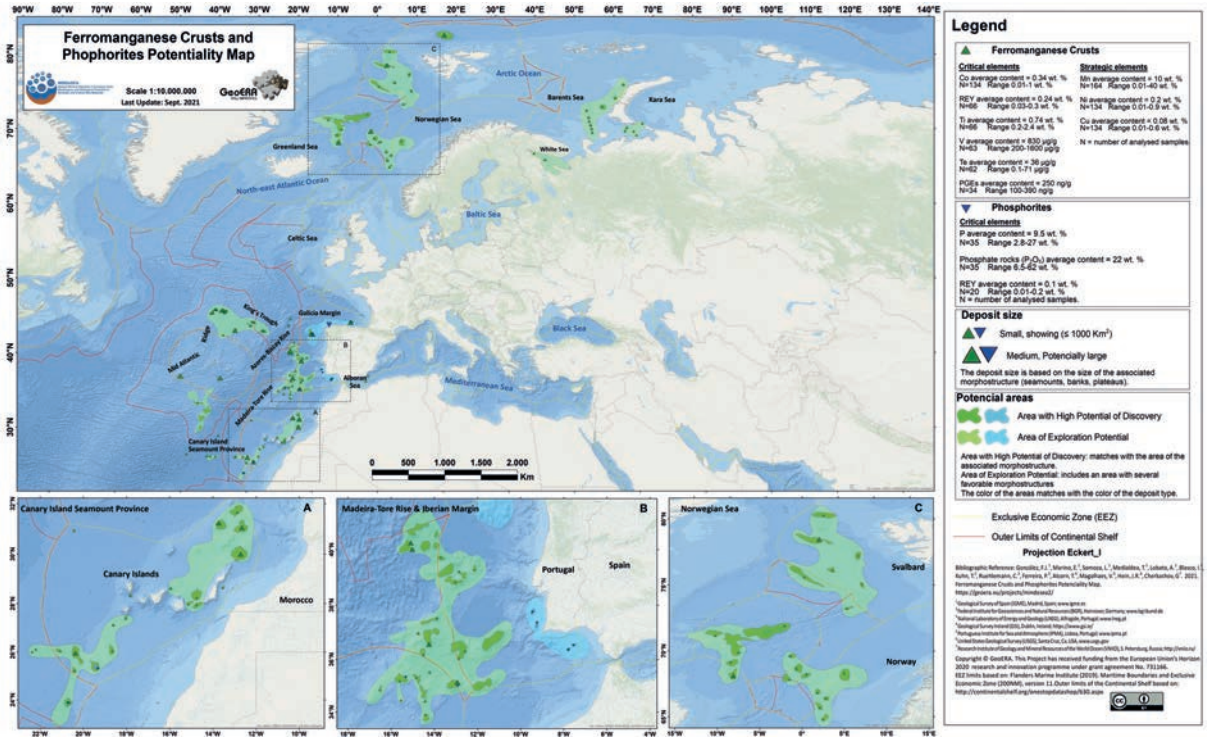

Figure 2.8: *Predictive map of Co-rich ferromanganese crusts and phosphorites in pan-European seas (González et al., 2021a); source MINDeSEA project.*

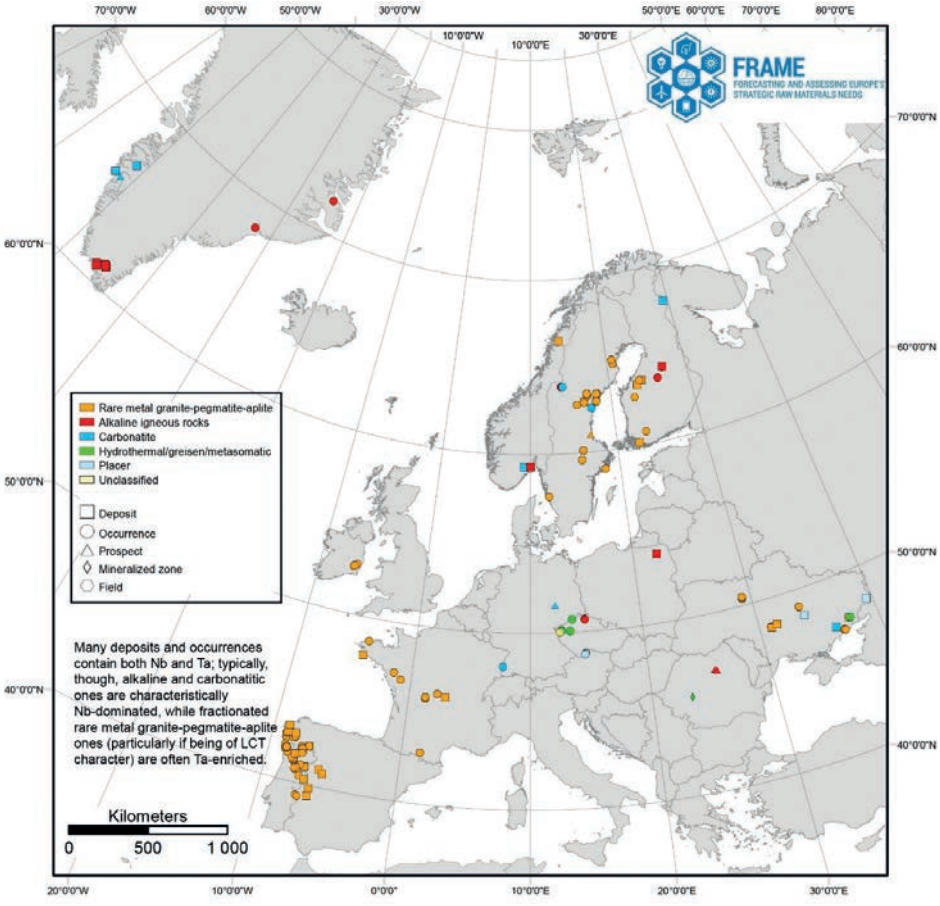

Figure 2.9: *Nb and Ta mineralisations in Europe grouped by deposit type. The map is based on data from FRAME's WP6 compiled from existing data in pan-European databases (Minerals4EU/MIN4EU, EURARE, and ProMine) as well as national geological survey databases. Additional data on some deposits originate from external sources and publications; source FRAME project.*

Viable primary sources of Nb-Ta in Europe are mainly deposits where Nb and / or Ta can be extracted as by-products of other mining / metal production. The on-going 'green' transition to an increasingly sustainable and carbon-neutral society has increased the demand for certain metals required for specific applications (e.g. Li for e-vehicle batteries and REE for e-vehicle traction motors, wind turbines and other electrical power generators), which has resulted in much interest on the near-future potential of different 'non-traditional' ore deposit types, such as European LCT-pegmatite systems. When or if Li production starts from the latter type of deposits, they could become future sources of Ta in addition to Li. Certain Li and/ or Sn-W deposits where Nb and / or Ta could be valuable by-products are also possible candidates for development, as in the cases of previously mined deposits in Spain and Portugal which have recently been subject to renewed interest from exploration and mining companies. Alkaline complexes and carbonatites in Greenland host large deposits including both Nb-Ta and REE. Some of these are currently being explored for Nb-(Ta), GlobelNewswire, 6. Nov. 2020.

2.4 Is there a life after mining? Historical mine sites

Since the dawn of civilisation, metals, stone and other mineral resources have been exploited for the benefit of human development. More than 10 000 years of quarrying and mining has left significant imprints on the European landscape. The history and development of modern society has been designated by the principal materials used at the time. The stone age, bronze age and iron age are explicitly linked to minerals. Progress through the industrial revolution and the modern industrial age, including today's computer age are reliant on coal, oil, silicon and other elements of which several were discovered in the 19th and the 20th century (e.g. indium in 1863 and gallium (Ga) in 1886 by spectroscopy, hafnium (Hf) in 1923 by X-ray spectroscopy). Gradually, the diversity of geological resources exploited to serve technological development has increased, and virtually every element of the periodic table has a modern industrial use often locked in complex components (see Chapter1). The use of mineral resources has been key to solving problems through history, and today this is more important than ever. It will also be in the future, although a larger portion will be obtained through recycling. As society transitions towards a low carbon and renewable energy future, there has been increased high level recognition of the strategic and societal importance of key raw materials. This has not always been reflected at a societal level and there remains a significant disconnect between consumers and the sourcing of the raw materials.

In GeoERA RM, the role of historic mining and quarrying sites is twofold. Firstly, as sites of learning about our use of minerals through history. Secondly, as possible sources of minerals and metals that we need today. In some cases, minerals and metals that we need today were not recovered when the mine was operating in the past either because those materials were not needed in the past or the older technologies could not extract these. With new technologies we may be able to harvest historic mine waste materials for metals and minerals that we need today.

2.4.1 Post mining options

> *"The new trash is the new cash"*
>
> *(Maroš Šefčovič, Vice-President for Inter-institutional Relations and Foresight, European Commission,speech at RMW2021.*

Across Europe, there are many modern examples of beneficial post mining uses. In some cases, historic mine sites which had suffered environmental degradation, as a result of weaker regulation, lack of understanding of the impact of mining activities or lack of technologies to deal with environmental damage or issues, have been rehabilitated. Such examples range from rehabilitation with no trace of prior mine workings to examples which proudly present historic mine sites as part of our cultural heritage including workers' identity. MINTELL4EU

examined historic mine sites from an educational and recreational point of view and looked into aspects of heritage and tourism (see also section 3.1.5). FRAME, on the other hand, focused on the potential critical raw material endowment which may exist in mine waste stockpiles across Europe.

The European Commission stated in the 3rd Edition of the Raw Materials Scoreboard for the reference year 2017(European Commission, 2021c):

"Despite their high economic and strategic importance, metal ores only represented a minor proportion of the EU's material consumption in terms of mass. 46% of metals (0.25 Gt) came from imports. Domestic extraction was divided into pure metal (0.02 Gt) and extractive waste (0.19 Gt), which become end-of-life waste (typically accumulated in tailings). Domestic recycling accounted for 23 % of metals processed in 2017 (0.08 Gt out of 0.35 Gt, excluding extractive waste). In 2017, 24 % of processed metals were integrated into societal in-use stocks, and the same percentage was exported (0.13 Gt)".

These figures provide the stimulus to revisit historical mining sites to examine their potential for CRM (Figure 2.10). In addition, if such waste poses threats to the environment which need to be addressed then the reworking of these waste may also tackle the environmental issues. The rehabilitation of these sites can be coupled with the recovery of needed raw materials, if present, and thus support the Circular Economy paradigm (Figure 2.11).

- **Managed waste storage:** In many cases, complete and faithful restoration of a site to its prior use is impractical or often impossible. This often means that a site requires ongoing management of facilities such as tailings impoundment or waste tips, and ongoing activities such as water treatment. Part of this management may include the extraction of raw materials on the site which could be contained in waste tips or tailings impoundments. Most mine waste sites are related to abandoned mines and here is often little information on the site itself, on the processes used to extract the minerals, or any engineering data on the construction of the tips or tailings facilities. This lack of information makes it difficult, if not impossible, to assess the site for any raw material potential. Especially with regard to CRM data is missing as they were not extracted, or even known, at the time of mining activity. Some of these historic mine sites have been

Figure 2.10: *Tailings from copper flotation at Rehova, Albania; photo courtesy of Henrike Sievers – FRAME project.*

examined, mainly by taking random samples for analysis to improve data availability and contribute to a broader knowledge of the sites' potential. Within the FRAME project a case study on the Riddarhyttan mining field in Sweden showed that the mine waste in the area contain elevated values of CRM. Especially the tailings at Källfallet are rich in molybdenum (Mo) and REE, on average 280 ppm Mo and 0.25 % REE (Hallberg and Regeniussen, 2021). Nevertheless, systematic sampling of mine wastes would be needed to fully assess the raw material potential.

The case study of the Litija mine in Slovenia depicted that despite indications that sphalerite in Litija contains elevated levels of CRMs such as Co, Ga, germanium (Ge), their levels in the bulk samples were relatively low and the potential for their extraction is insignificant Teran K (2021).

Since reprocessing of mining waste material on the Litija area is unlikely to happen, they need to be remediated in the future. Their uncontrolled weathering and erosion may introduce significant amounts of potentially toxic elements (e.g. quicksilver (Hg) and lead (Pb)) into urban soils, sediments, airborne particulate matter, and water bodies. The case study conducted can therefore raise citizens' awareness of historic environmental hazards in their local area, as well as assist local and state officials in making decisions for a healthier environment Teran K (2021).

The reassessment of these historic mine sites indicated that the majority of them are no longer accessible due to rehabilitation, removal, post mining development over the sites, cultural heritage protection, or are (too) small in terms of volume. Case studies considered the most obvious and accessible sites. However, reworking of the mine waste might be prudent when considering environmental, societal and economic aspects in a holistic study. The historic mine sites data has been compiled in case studies accessible through EGDI.

- **Heritage and tourism development:** As the key driver of societal and technological development, the availability and sourcing of raw materials over time is a fundamental aspect of the history and progress of civilisation. Sites which have played a significant role in local, national and global development over the past centuries have been conserved in places, often fortuitously. In modern times there has been a drive to conserve and protect these sites as educational or heritage assets. Examples occur throughout Europe and include the former copper mining district of Røros in Norway which is recognised as a UNESCO World Heritage Site since 1980 and the historical Lousal mine site, Portugal (Figure 2.12; Figure 2.13).

***Figure** 2.11: Re-mining of chromite tailings at Bulqiza, Albania; photo courtesy of Henrike Sievers – FRAME project.*

Figure 2.12: *View over the town of Røros, Norway from the dumps of the former copper mine in the town; photo courtesy of Henrike Sievers – FRAME project.*

Figure 2.13: *View of the Lousal open pit (foreground) and the mine dumps, headgears and ore processing plant in the background. Photo courtesy of Daniel de Oliveira.*

For the sake of completeness rehabilitation and non-mining industrial use are briefly mentioned below, which were hardly considered in the GeoERA framework.

- **Rehabilitation to prior use:** Many former mine sites across Europe have no modern trace left within the landscape and have been returned to prior use, for example agriculture or forestry. Modern mining rehabilitation takes place under well-structured conditions and in a concise legal framework within the European Union. A holistic and transparent rehabilitation strategy can add to improve the social acceptance to operate. What might be considered today worth to achieve full rehabilitation without a trace might be a considerable resource of tomorrow.
- **Continued non mining industrial use:** Mine sites require significant infrastructural development including transport links, power supplies and water sources. Hence, many past mine sites in Europe have paved the way for further development. Following exhaustion of the mineral reserves, these sites can act as attractive locations for alternative industrial uses. This can also mitigate the potential job losses and economic impact of a mine closure. Examples of successful post mining transitions include the UNESCO World Heritage Site 'Zeche Zollverein' a coal mine industrial complex in Germany, and the Lisheen mine site in Ireland. The community adjacent to the mine requested that the post closure plan be altered to retain the industrial facilities including the regional water supply and the wind farm to facilitate the attraction of alternative industry. The site now hosts Ireland's National Bioeconomy Campus and is a key location in Ireland's transition towards a more circular and greener economy.

  The recent green deal targets calls for further rehabilitation of former coal mining sites across Europe.

Towards a large REE mine?

Fe-dolomite carbonatites in the Fen Carbonatite Complex in Telemark, Norway, has for some years been known to host abundant REE-minerals. Detailed mapping by the Geological Advisor to the Telemark Vestfold County combined with early stage exploration by a prospecting company revealed a potential for near-surface ore grade qualities. With support from the Norwegian Government, the Geological Survey of Norway, in collaboration with the Geological Advisor to the county, conducted deep core drilling in 2017 to test the possible continuation of the Fe-dolomite carbonatite at depth. Two rock cores of 1001 meters and 716 metres were recovered showing ore bearing carbonatite down to the bottom. The results were openly published, and private companies are now investing in extensive exploration activities and pilot beneficiation tests. The results so far are promising with exploration target counted in billion tons.

The Fen project is an example of how governmental funding of mapping and research drilling brought forward sufficient new information for triggering private investments in exploration. Although this project can serve as an example of a fast-moving mineral exploration project, the most optimistic forecast for mining is 2030. This implies a total of 15 years from targeted public mapping to mining.

Further reading: NGU (2019)

REE-rich ore in drill core showing REE minerals with brownish colour. Photo courtesy Tom Heldal, NGU

3 Comparable and reliable data

„Europe need data and data needs care“

(Riikka Aaltonen, 20 January 2022 – Final Event)

In most European countries there is a long tradition of collecting data on raw materials. From mapping and estimating resources in the field, compiling national statistics related to production and trade, collecting data on resource and reserve estimates, to (more recently) surveys related to secondary materials. The geological surveys play an important role in curating and in some cases collecting these data through field work, mapping and laboratory analysis of samples. In some cases, they also compile these data from other responsible entities such as governmental ministries and make data available in different formats.

3.1 European database on mineral resources, MIN4EU

Although national maps, estimates and overviews of raw material occurrences may have a long history, they were often conducted under different (legislative) backgrounds, and addressed different issues. Hence, they are not necessarily comparable across borders. Several projects and initiatives have addressed this issue, the most recent being the GeoERA MINTELL4EU project that has updated the electronic Minerals Yearbook (production, trade, resources, and reserves) as well as the Minerals Inventory (mineral occurrences and mines quarries included). MINTELL4EU has integrated these two datasets into one central database, called MIN4EU, enabling visualisation and open access on EGDI.

In the following sections, the data types available in MIN4EU and visualised through EGDI are described. They also describe how the data were collected, and for some data types, how they will continue to be updated. We believe that the MIN4EU database is currently the most comprehensive and harmonised raw materials information database in Europe, with the potential to grow further in the future.

3.1.1 The European electronic Minerals Yearbook

Aggregated national data on production, trade, resources, reserves, and exploration at commodity level are of interest to policy makers and other stakeholder groups, such as industry, authorities at national, regional or local levels, and at a European level. These data can be used to provide information on different aspects of mineral supply chains, such as dependence on imports, domestic production and how this compares to the global market, the potential for future production to supply and support domestic manufacturing, for example.

To establish a harmonised overview of these data types, the electronic European Minerals Yearbook (e-MYB) was developed during the Minerals4EU project (2013 – 2015), supported by the FP7 programme. Minerals4EU compiled data covering the period 2004 – 2013. A continuation of this work, updating the e-MYB, was designed and implemented within the MINTELL4EU project of GeoERA (2018 – 2021). MINTELL4EU collated data from 2014 – 2019, and integrated these with the Minerals Inventory, which allowed the amalgamation of the e-MYB data into the central MIN4EU database.

The e-MYB contains data for primary mineral production, imports, exports, resources, reserves and exploration. It also contains data on secondary materials (mineral-based waste generation, treatment and trade), mainly collected during Minerals4EU. In total, it covers more than 60 mineral commodities (Deady et al., 2021).

Production data are collected by the BGS who have collected and collated production data for more than 100 years. These data are stored in a BGS database from which an annual publication 'World Mineral

Production' is produced. Data collection involves a team of skilled geologists and data analysts, who have extensive experience with mineral statistics. A range of organizations in each country, including but not limited to government ministries, geological surveys, trade associations, statistical offices and other relevant organisations are contacted, and data requested. In addition, country experts search for documents on websites of organizations and publicly listed companies. Country experts review and revise existing data and are constantly searching for improved datasets or potential new data sources. Finally, BGS staff then fill in the remaining gaps using secondary sources of information or estimates, informed by available statistics. This means that in most cases, data are gathered from multiple sources for each country as data rarely sit in national central databases where information can be automatically and freely downloaded or harvested. During the MINTELL4EU project, partners were asked to verify data collected from their countries.

Trade data (Imports and Exports) are purchased from a third party by BGS, as purchasing these data speeds up the process of gathering the volume of data needed to accurately portray mineral trade. These data are then assessed by a small team of data analysts on both a commodity by commodity and a country-by-country basis to ensure consistency and completeness and divided by trade type. Data quality is tested by consulting other online databases such as UN Comtrade or Eurostat, checking for any anomalous looking data or filling in any gaps. The compilation of data from different sources into one BGS-hosted database, along with careful quality assessment, provides the most complete and accurate dataset for mineral trade.

Mineral production data as well as mineral **trade data** for the period 2004 – 2019 are available for 40 countries, see Table 3.1.

Data on **Resources** and **Reserves** are available from different sources and at different scales, but for the e-MYB, the focus was to collect, where possible, data from GSOs as these are considered to be best placed to provide reliable data. Data were collected on a country-by-country basis through the provision of data on individual commodities. Resources and reserves data were first collected by the Minerals4EU project (with a reference year of 2013) by means of a one-off Excel-based survey that was sent out to individual partners and data providers and compiled centrally. This survey was repeated in the MINTELL4EU project (reference year 2019) but using an online digital survey form instead with the aim of improving consistency and allowing an easier method of data handling and quality control once collected. Data providers were given the option to provide data in different forms, namely CRIRSCO-compliant data on resources and reserves, historical data, or other types of national non-CRIRSCO-compliant data. Providers could also provide data using the United Nations Framework Classification (UNFC) format. Each (non-UNFC) data entry typically comprises Commodity Name, Amount, Classification Method Used, Category, Comments. Not all countries were able to provide data, however, data collected in Minerals4EU with a reference year of 2013 are still available to view in EGDI.

Mineral **resources and reserve data** with a reference year of 2019 were provided by 17 countries in MINTELL4EU, see Table 3.1.

Data on **exploration** activities were collected in the same way as the resources and reserves data. Many data providers were unable to deliver these data as they are often handled by other authorities or entities than the GSOs. Only seven countries provided exploration data, see Table 3.1.

Table 3.1: *Overview of countries providing data for the e-MYB (production, trade, resources, reserves, exploration) and the Minerals Inventory (mineral occurrences and mines (quarries included)). Brackets indicate that data were not updated during MINTELL4EU but was collected by the Minerals4EU project and have been transferred to the MIN4EU database.*

MIN4EU							
	Electronic Minerals Yearbook [e-MYB]					Minerals Inventory	
Country	Production	Trade	Resources	Reserves	Exploration	Mineral occurrences	Mines
Albania	x	x	x	x	x	x	x
Austria	x	x				x	x
Belgium	x	x	x			x	
Bosnia & Herzegovina	x	x				x	x
Bulgaria	x	x					
Croatia	x	x			(x)	x	x
Cyprus	x	x	x[a]	x[a]	x	x	x
Czechia	x	x	x	(x)	(x)	x	x
Denmark	x	x	x[a]	x[a]	(x)	x	x
Estonia	x	x	(x)	(x)	(x)		
Finland	x	x	x[a]	x[a]	x	x	x
France	x	x	x			(x)	(x)[d]
Germany	x	x				b	b
Greece	x	x	(x)	(x)	(x)	(x)	(x)
Greenland	x	x	x[a]	x[a]		x	
Hungary	x	x	x		x	x	x
Iceland	x	x					
Ireland	x	x	x	x	(x)	x	x
Italy	x	x		x	x	x	x
Kosovo	x	x	(x)	(x)	(x)		
Latvia	x	x	(x)				
Lithuania	x	x	(x)				
Luxembourg	x	x				x	x
Malta	x	x					
Montenegro	x	x				x	x
The Netherlands	x	x			(x)	(x)	(x)
North Macedonia	x	x	(x)	(x)	(x)		
Norway	x	x	x	(x)		x	
Poland	x	x	(x)	(x)	(x)	x	
Portugal	x	x	(x)	(x)	(x)	x	x
Romania	x	x	(x)	(x)	(x)	(x)	
Slovakia	x	x			(x)	x	x
Slovenia	x	x	x[a]	x[a]	x	x	x
Serbia	x	x	(x)			x	x
Spain	x	x	x[a]	x[a]	x	x	x
Sweden	x	x	x	x		x	x
Switzerland	x	x			(x)	(x)	(x)
Turkey	x	x	(x)	(x)		(x)[e]	
Ukraine	x	x	x[a]	x[a]	(x)	x	x
United Kingdom	x	x	x[a]	x[a]	(x)	x[c]	

Notes. Letters code: (a): Data delivered in UNFC format; (b): One German state delivered data. Outside this state, one German data point was collected in the EURare project; (c): Only as occurrence areas; (d): Only closed mines/quarries; (e): Only a few data points collected by others in the EURare project. Colour code: white – no entry; yellow – the whole country not covered only one state of a federal country; pale orange – up-dated entries; orange – latest update in 2013.

3.1.2 The Minerals Inventory

The location of mineral resources, either in already established mines (quarries included) or as deposits or occurrences in the landscape, including information on the estimated quantities of commodities of interest, are of interest to policy makers at national and international level, to mining companies as well as to citizens. To the extent that the regional or national geological surveys are authorised to share this information, the location and associated data on mineral occurrences and mines (quarries included) are published at EGDI. The full MIN4EU database, where these data are stored, is freely accessible and available to all interested users (see also section 3.1.3 on license issues).

Efforts to make these data available, and to establish what is often referred to as 'the European Knowledge Base on Raw Materials' or, as others prefer, the 'Mineral Intelligence for Europe' started more than a decade ago (see chapter 1 on previous and parallel projects). The vision was, and still is, to establish a fully automated system in which data on raw materials would be collected electronically and regularly ('harvested') from each data provider (a GSO or other data holder e.g. a ministry or agency) and stored in the central MIN4EU database (Kumelj et al., 2021). Collecting data in this way ensures that the data in EGDI are always as up to date as possible. The harvesting routine, see below, was first developed and partially implemented in the Minerals4EU project and further extended in MINTELL4EU. As of November 2021, 31 European countries (see Table 3.1 and Figure 3.1) provide data to the MIN4EU database, enabling visualisation on the EGDI platform. The coverage, as shown in Figure 3.1, in the EU is getting closer to complete, as only Bulgaria, Estonia, Latvia, Lithuania, Malta as well as some German states are not covered, while a large number of non-EU parties have shared their data

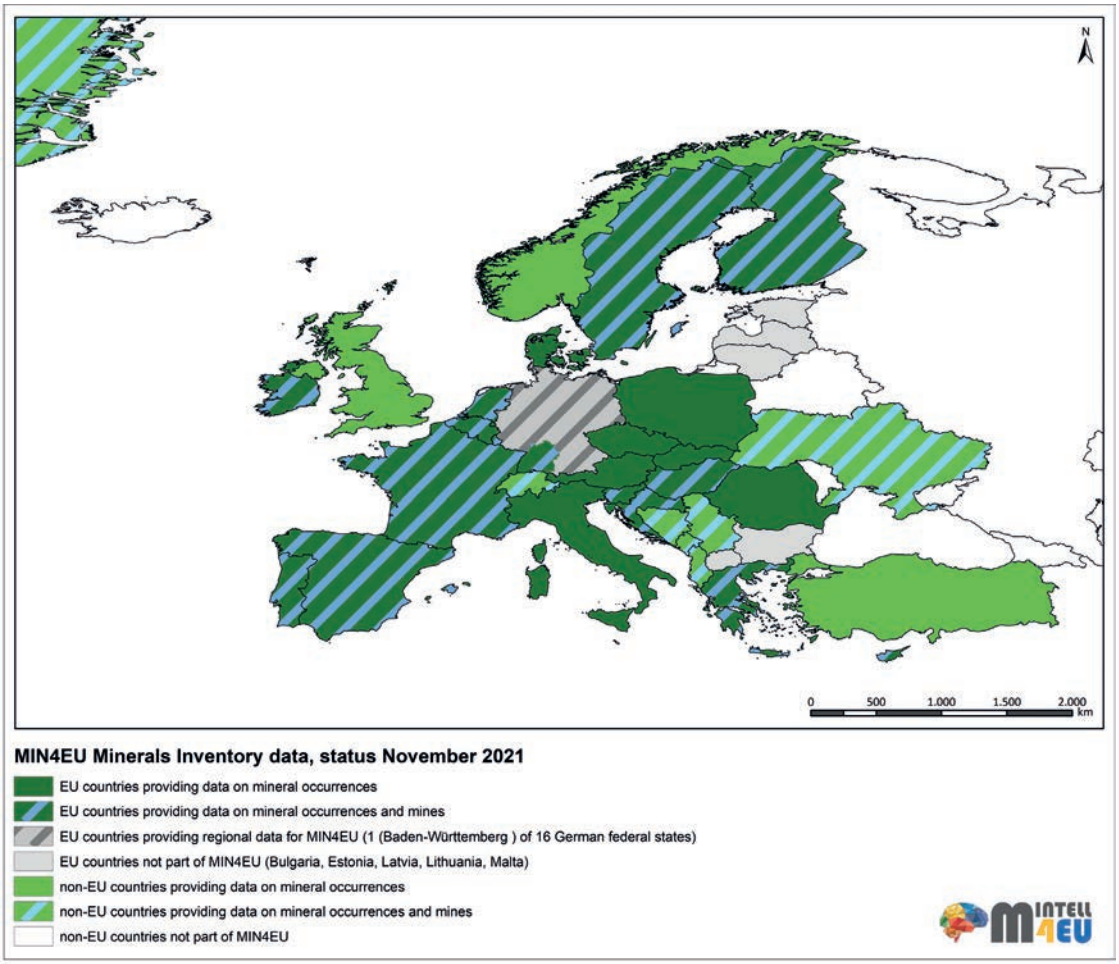

Figure 3.1: *Overview of countries sharing data on mineral occurrences and mines (Minerals Inventory).*

(e.g. Norway, Ukraine, the UK and West Balkan countries). At this stage, not all countries deliver their data through this automated harvesting routine. Instead, they provide their data in a static format (Excel, Access, etc.) which is then hosted (and harvested) by those surveys that maintain the harvesting routines and database (GeoZS and GEUS). The weakness of this latter solution is that ongoing updates are not necessarily included in these stationary files which are only likely to be updated in future dedicated projects, as Minerals4EU and MINTELL4EU were in the past.

The e-MYB and Minerals Inventory in particular are associated with this harvesting system and are dependent on technical information and guidelines developed in the ORAMA project (Bide et al., 2019). This was crucial for improvements in data collection and their successful implementation. Data providers need to remember that their data needs to be easily accessible and understandable, as well as reliable and of a standard quality. They need to set up a routine for developing data at the national level supported by sufficient and appropriate datasets. To be able to achieve this, they need to understand the overall technical process that underlies it. This can only be achieved by strong communication and cooperation among mineral resource and IT specialists as their mutual collaboration is imperative for sustainable web services.

When it comes to data flow, MINTELL4EU implemented an architecture with a harvesting and distribution system (Figure 3.2). The system is structured in three parts and is adopted from Cassard et al., 2014:

1. At a national level data must be organised in an INSPIRE compliant way. This enables the WFS (Web Feature Service) Interface Standard to deliver data to the harvesting system either from structured databases or directly from other data sources in each country.
2. A central harvesting system regularly requests and reads data from the national WFS and stores them in a 'Harvesting Database'. Data are subsequently delivered to the central database (MIN4EU). The Harvesting Database is optimized to the read data from the national level and then delivers these data MIN4EU.
3. MIN4EU (with updated data from the harvesting system) provides data to users through EGDI. MIN4EU is optimized to provide a better experience to the user for the delivery of data and the computation of on-demand services. Data is visualised through EGDI in a set of predefined maps that can be edited. From EGDI, the full database is also downloadable.

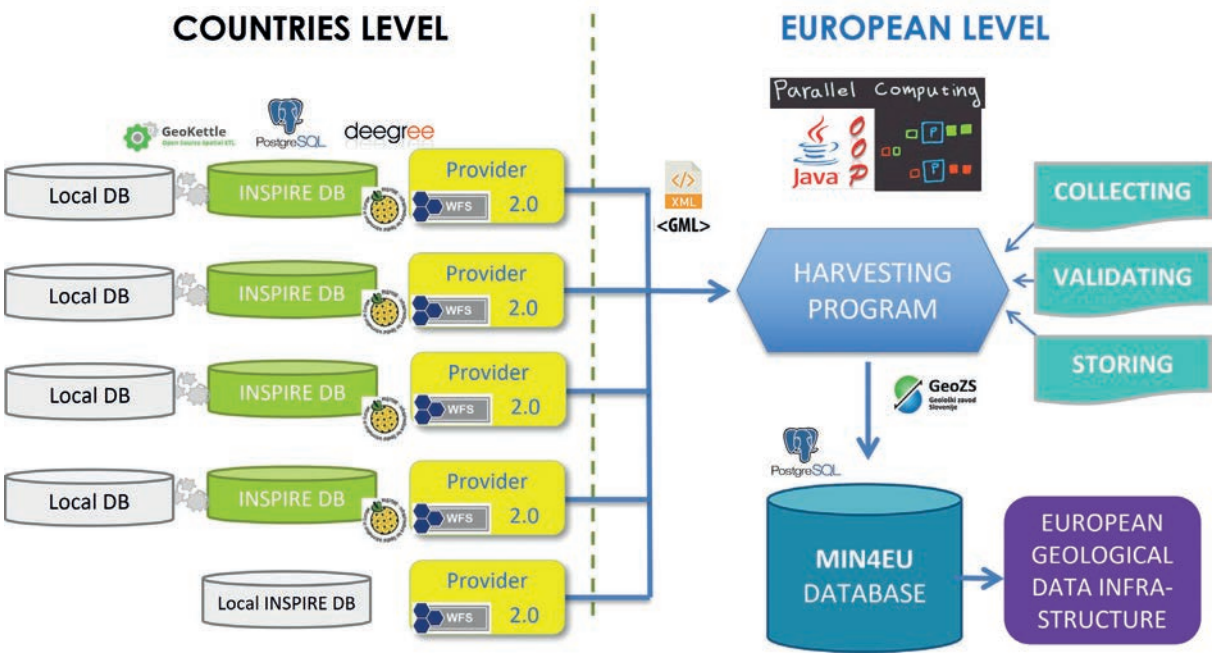

Figure 3.2: Harvesting and distribution system architecture.

The **harmonisation of data**, although well advanced, is an endless task. Although several workshops have already been held and numerous guidelines and training materials have been produced, there are still different interpretations and understandings of terms. To address this key issue, it is extremely important to maintain and further develop the strong network and communication between data providers, and to continue development of all users.

3.1.3 License issues

As mentioned above, the full MIN4EU database can be downloaded from EGDI, currently in the form of an SQL-database/GeoPackage. Future developments will allow the downloading of data displayed on maps, e.g. when a user selects one or more specific commodities. The data are subject to a license, in most cases the Creative Commons License (CC-BY) license that allows the user to copy and augment the data with other information whilst acknowledging the source of the original data (CC-BY, without date). The licensing is described in more detail in the respective metadata for the e-MYB and for the Minerals Inventory.

3.1.4 The UNFC and UNRMS

With the global increase in raw material demand comes the need for harmonized support tools for sustainable resource management in Europe. Reliable and transparent national and pan-European mineral resource data are needed to improve the understanding of resources in the EU, to diversify the supply base, from both new primary and secondary resources. In addition, sustainability principles need to be adopted to support mineral policy decision making.

European countries and the EU need to assess their resource potential regularly. However, European countries have not had a common tool to aggregate information for a continent-wide resource inventory. As mentioned above, the first European database on raw materials was established by the Minerals4EU project where several different reporting codes were used, making it difficult if not impossible to make cross-national aggregations. In ORAMA (Bide et al., 2019) and MINTELL4EU (Simoni et al., 2021; Hokka et al., 2021), our hypothesis was that the **United Nations Framework Classification for Resources** (UNFC, 2020) can support this by facilitating the harmonisation of mineral resource data. The work from ORAMA have been further elaborated in UK (Bide et al., 2022).

In MINTELL4EU, we wanted to test if the national geological surveys could use UNFC as a tool to evaluate a country's known and potential resources, and to determine if the UNFC could provide a satisfactory tool for the harmonization of mineral resources nationally and across Europe. With this in mind, a pan-European pilot study comprising UNFC case studies for a selection of commodities in different countries was implemented in MINTELL4EU. The objectives were to assess the status and key challenges concerning the application of UNFC across Europe, and to develop further recommendations for optimizing resource classification and aggregation procedures using the UNFC (Hokka et al., 2021).

19 case studies from nine different countries were carried out to test and assess if the UNFC could be used to harmonize and aggregate resource data (Table 3.2). The case studies are described in Simoni et al., (2021) and can be found on EGDI as a separate map layer.

These case studies are extremely informative and are useful for planning future resource compilation work. They also include potential breakthroughs in the use and application of the UNFC system. The case studies included national aggregated data, regional and local assessments, as well as data with CRIRSCO-compliant and non-compliant mineral quantities. For the CRISCO-compliant assessments, the CRIRSCO–UNFC bridging document (UNECE, 2015) was used.

The results of the case studies demonstrate that it is feasible and meaningful to use the UNFC classification to classify different types of mineral occurrences with resource data in different countries according to their

environmental-socio-economic viability (E), technical feasibility (F), and degree of confidence in the estimate (G). However, the case study preparation was time-consuming and involved significant case-by-case manual data compilation, expertise, and familiarity with the UNFC system. In many cases, relevant information was known to exist but inaccessible to the GSO carrying out the case study, making it challenging to apply the UNFC. The case studies also showed significant variation in how evaluators quantified resources, interpreted the E-F-G criteria of the UNFC. Moreover, data confidentiality issues also affected the case study work and results, and some case studies had to be generalised because granular (i.e. site level) information could not be published.

Table 3.2: *Overview of MINTELL4EU UNFC pilot case studies classified by scope (national/regional/site) and granularity (aggregated/site). Case studies with square brackets [] have been prepared at site-level granularity but were made available by the issuing organisation only in a generalized form due to confidentiality constraints.*

Country	Au	Cu	Co	Mn	REE	Phosphate	Carbonates	Graphite	Aggregates	Natural stone	Peat	Gypsum	Perlite	Total
Austria	..	..	..	..	..	..	..	..	R	..	..	..	..	1
Belgium	..	..	..	..	..	n	..	..	..	..	..	..	..	1
Croatia	..	..	..	..	..	..	..	..	R	..	..	..	..	1
Denmark	..	..	..	..	..	..	N	..	N	..	..	..	..	2
Finland	N	N	N	..	..	..	..	N	..	..	R	..	..	5
Hungary	..	..	..	[S]	..	..	..	..	..	..	..	r	[r]	3
Norway	..	..	..	..	..	n	..	R	r	r	..	..	..	4
Slovenia	..	..	..	..	..	..	..	..	N	..	..	..	..	1
Sweden	..	..	..	..	r	..	..	..	..	..	..	..	..	1
Total	1	1	1	1	1	2	1	2	5	1	1	1	1	19

N: National, aggregated (7) n: National, site (2) R: Regional, aggregated (3) r: Regional, site (6) S: Site, site (1)

A flow sheet on how to use the UNFC for individual sites or regional studies was developed based on the results of a review of the MINTELL4EU case studies (Simoni et al., 2021; Hokka et al., 2021) (Figure 3.3). The workflow can be used to decide what to consider when carrying out a UNFC project and to communicate challenges with integrating data into national or international inventories. One key aspect is that the roles and responsibilities of different UNFC stakeholders and users need to be clarified both on a national and EU level, particularly with regards to data management and disclosure. This primarily concerns data providers, commercial operators, and government organisations directly involved in collection, evaluation, and management of mineral resource information, but also includes associated professional and industry umbrella associations, and pan-European data providers.

Consistent and comprehensive national UNFC inventories and Pan-European resource estimates and accounting cannot be achieved unless national jurisdictions mandate the use of UNFC and enforce appropriate public disclosure and reporting to GSOs and other relevant public authorities (Figure 3.3). In other words, a full UNFC reporting of aggregated national project results cannot be achieved before all data are open and accessible.

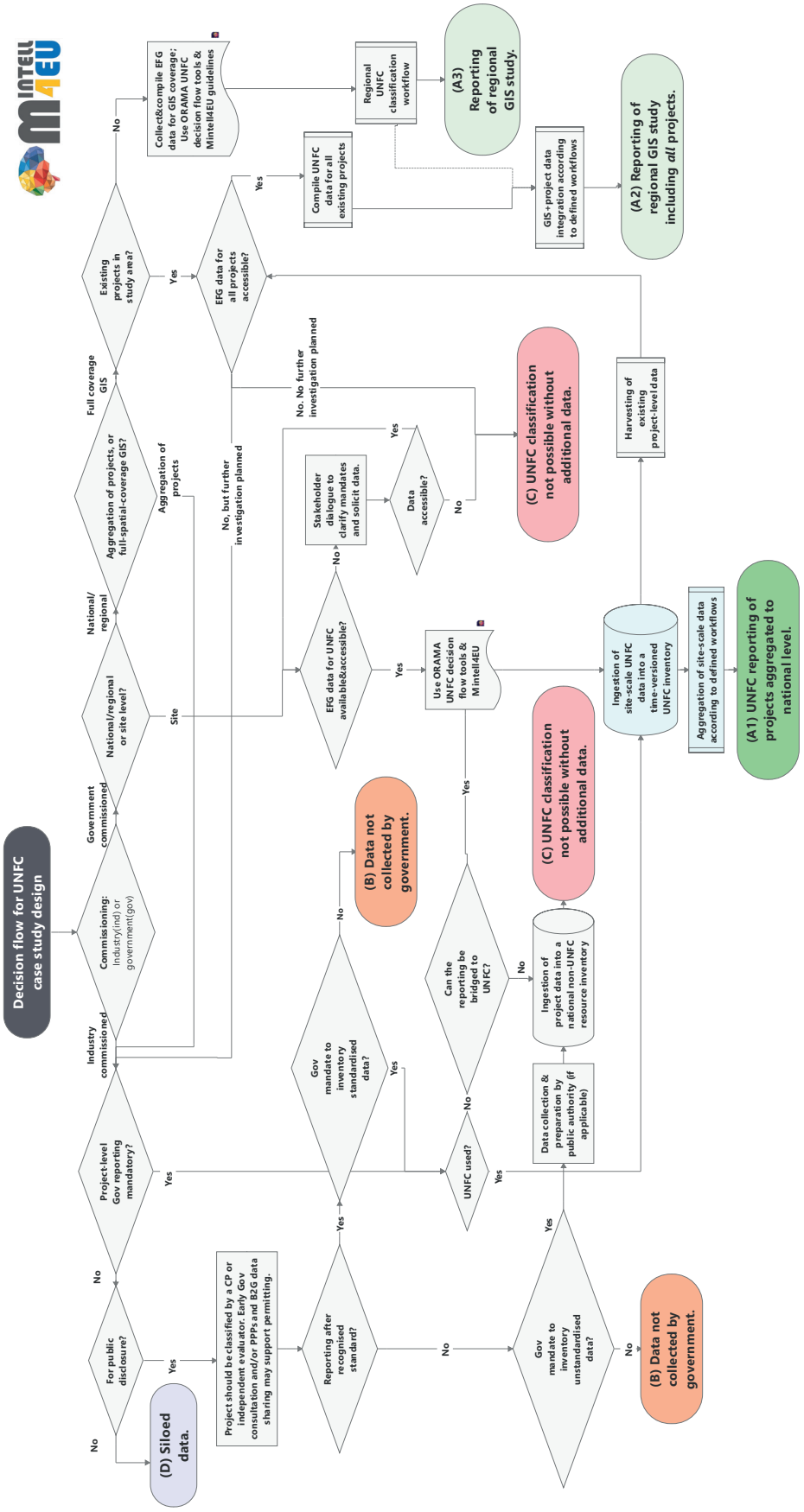

Figure 3.3: *Flowchart on the use of UNFC in classifying mineral resources (from* SIMONI *et al 2021).*

To summarize, MINTELL4EU has identified the following challenges that need to be dealt with in order to compile mineral resource data according to the UNFC:

1. National and international policy frameworks are needed to overcome poor data availability and accessibility.
2. Data compilation and classification procedures as well as UNFC reporting templates must be developed to improve reporting standards and facilitate automation.
3. There must be a common, harmonized understanding on how to apply the UNFC. Extensive training is required to overcome the lack of a common understanding of the UNFC system and to assist in providing more transparent, comparable, and reliable results. Such training should be available to all UNFC practitioners, as indicated in item 5, below.
4. National mineral resource accounting practices, (i.e. production of and maintaining aggregated resource data at a national level), needs to be uniform across countries to assist in attaining aggregated data which are realistic and complete on a pan-European scale. Relevant E-F-G data needs to be collected and made available in a suitable interoperable format.
5. To achieve harmonized data, it is necessary to create a permanent pan-European instrument for training in standardized mapping of national raw material resources and related data according to the UNFC system.

The work in MINTELL4EU confirms that UNFC indeed can be used as an international standard for resource classification. Using the UNFC for classification across different types of resources and countries is both feasible and meaningful, and potentially contributes significantly to achieving global sustainable development and EU raw material policy objectives.

The **United Nations Resource Management System** (UNRMS) is complementary to the United Nations Framework Classification for Resources (UNFC). It was conceived as an integrated management system for resources in the energy and minerals commodities sectors and has since been extended to other resources including anthropogenic deposits, and groundwater resources. It aims to provide fundamental principles of good governance that can be applied by stakeholders at different levels – national, regional and project level – when managing natural resources (UNECE, 2021). The UNRMS aims to be a voluntary global standard for integrated resource management within the framework of public, public-private, and civil society partnerships that is uniformly applicable to natural resources and to anthropogenic resources.

In comparison to traditional resource management on a project-by-project or sector-by-sector basis, the UNRMS takes the bird's eye view to provide an overview of primary and secondary resources encompassing a wide range of knowledge and viewpoints. With the main objective of mitigating risks and supporting optimized and balanced sustainable resource management in the face of a myriad of challenges UNRMS is designed as a unifying framework for the integrated management of resources. UNRMS embraces the critical concept of integrated resource management that considers complexity, multiple scales, and competing interests, and brings these together to make informed decisions (CCA, 2019). UNRMS takes account of complexity, multiple scales and competing interest and balances all aspects to arrive at informed decisions. The UNFC, with its indicative information on socioeconomic viability, project feasibility, and resource management (discovery to post-closure), forms the core of the UNRMS, which is complemented by information on sustainable resource development in the UNRMS (UNECE, 2021). Thus, UNRMS and UNFC complement each other.

GeoERA projects provide a knowledge base that can be used to comply with UNRMS principles. Through the GeoERA Information Platform Project (GIP-P), the combination of information and data from different perspectives has been made possible. This means that maps on raw materials, groundwater, geological fault systems, energy, land-use issues, etc. are illustrated and accessible through EGDI. It can serve as a central entry point to provide some of the necessary baseline information. Efforts have been made by the GeoERA Raw

Materials projects to harmonize data and develop a common language and guidance for the provision and use of minerals data in UNFC for primary and secondary resources, taking into account FAIR[3] principles.

3.1.5 Maps and data

As described above, it has been a European-wide effort to update, supplement and harmonize data from many providers. These data are illustrated through maps in EGDI, where a dedicated viewer has been designed and developed for mineral resources and the e-MYB as two separate themes which can be combined. The displays use INSPIRE symbology (INSPIRE, 2013), and the information published is comprehensive while the system will facilitate the future addition of data and general maintenance.

The **Electronic-Minerals Yearbook theme** includes layers showing statistics for European countries on commodity production (Figure 3.4a), imports (Figure 3.4b) and exports (Figure 3.4c), documented mineral reserves and resources (Figure 3.4d and e), some categorized using the UNFC. Regarding production, imports and exports, users can create commodity-specific maps by selecting a commodity and a year from 2004 to 2019 and create time series for multiple countries for a given commodity type, an example is given in Figure 3.4a-f. It should be noted that 'production' covers data for nationally produced minerals (Figure 3.4a), while the trade data hosts information on primary production, refined and smelted metals. Itis important to recognise that exports of metals may not be mined or produced in the country originally, e.g. Belgium was the largest exporter of bismuth metal in 2018 (Figure 3.4f), but does not have any bismuth mining domestically, however, it does have a metal refining industry. Figure 3.4b displays import data for aluminium. Taking Germany as an example, the imported aluminium comprises data for both unwrought and alloyed aluminium. Figure 3.4c displays export data for all forms of copper. Taking Spain as an example, this includes data for copper matte and cement, copper unwrought alloys, copper unwrought unrefined, copper unwrought refined and copper ores and concentrates (gross weight). The **Mineral Resources theme** viewer displays several datasets on mineral occurrences, occurrence areas, mines (quarries included) and tourist mine sites. The mineral occurrence layers (one presenting point data and another showing areas) display all mineral occurrences and deposits and can be visualized by commodity deposits importance, by commodity group, or by commodity itself Figure 3.5a-b). Commodities that are included in EU's list of Critical Raw Materials (2020) are visualised in a separate layer for the convenience of interested users (Figure 3.5c).

3 **F**indability, **A**ccessibility, **I**nteroperability, and **R**euse of digital assets in the context of scientific data management; Wilkinson et al., 2015 https://www.go-fair.org/fair-principles/.

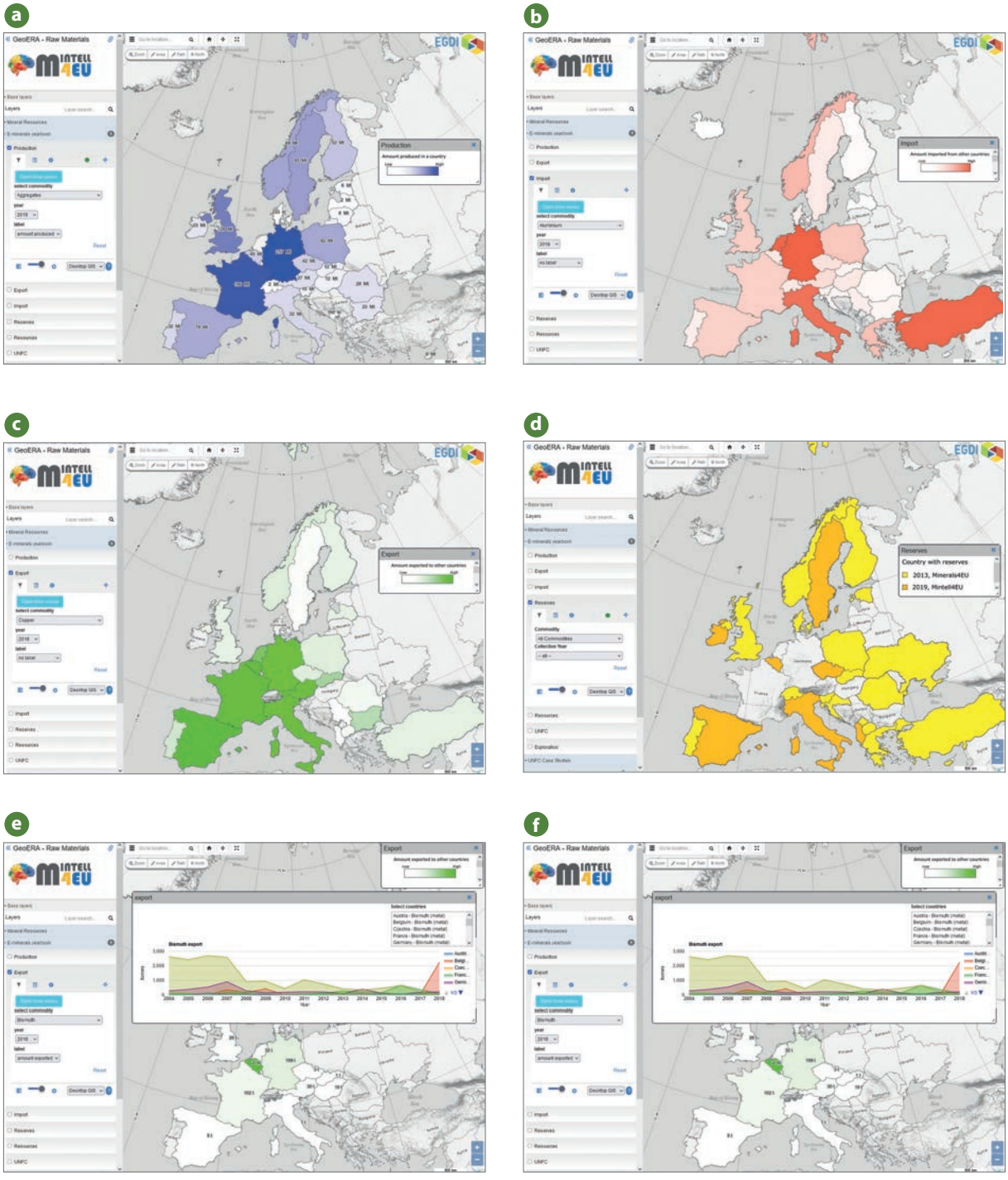

Figure 3.4 (a–f): *Examples of statistic information for European countries on commodity production compiled from data in the electronic Minerals Yearbook on (a) aggregates production in 2019; (b) aluminium (unwrought and alloyed) imports in 2018; (c) copper (all forms) exports in 2018; (d) documented mineral reserves collected in both Minerals4EU and MINTELL4EU (UNFC excluded); (e) UNFC classified resource and reserves data collected in MINTELL4EUs; (f) time series, here bismuth (metal) export. More details can be explored in EGDI –* https://data.geus.dk/egdi/?mapname=egdi_geoera_mintell4eu#baslay=baseMapGEUS&extent=-1591810,901180,7567380,5046670.

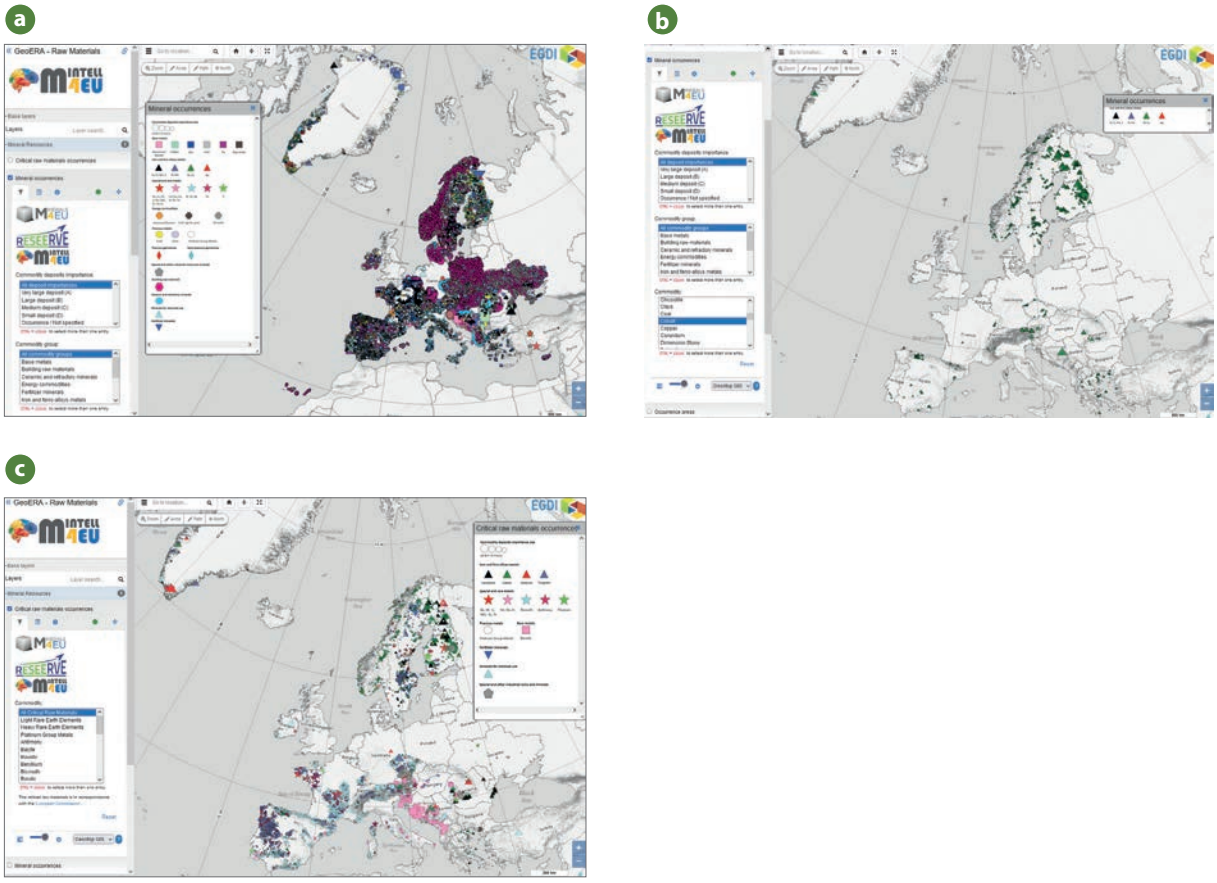

Figure 3.5: *(a-c). Mineral resources can be visualised by commodity groups or by commodity itself. The full coverage across Europe is shown in (a). To visualize all known deposits and occurrences in Europe of a specific commodity, this can be selected (b). Commodities that are included in EU's list of Critical Raw Materials (2020) are additionally visualised in a separate layer for the convenience of interested users (c). Symbology is INSPIRE-compliant. Ergänzung der Beschriftung um: More details can be explored in EGDI – https://data.geus.dk/egdi/?mapname=egdi_geoera_mintell4eu#baslay=baseMapGEUS&extent=-1591810,901180,7567380,5046670.*

Note that 'Importance' is a value indicating the ranked importance of a commodity compared to other commodities in the deposit. See INSPIRE definition https://inspire.ec.europa.eu/codelist/ImportanceValue.

The mines layer displays the location of open and closed mines (and quarries) as well as mines (quarries) under development. Users can display mines based on commodity, operational status or type of mining activity. In the general overview they are clustered in groups, but by zooming in, a user can search for an individual mine (Figure 3.6a). At all layers it is possible to click on individual points and see more details. Details will appear in a box often with links to more information, as in the Tourist Mine Site layer showing the location of historic mines that have been developed for tourism (Figure 3.6b).

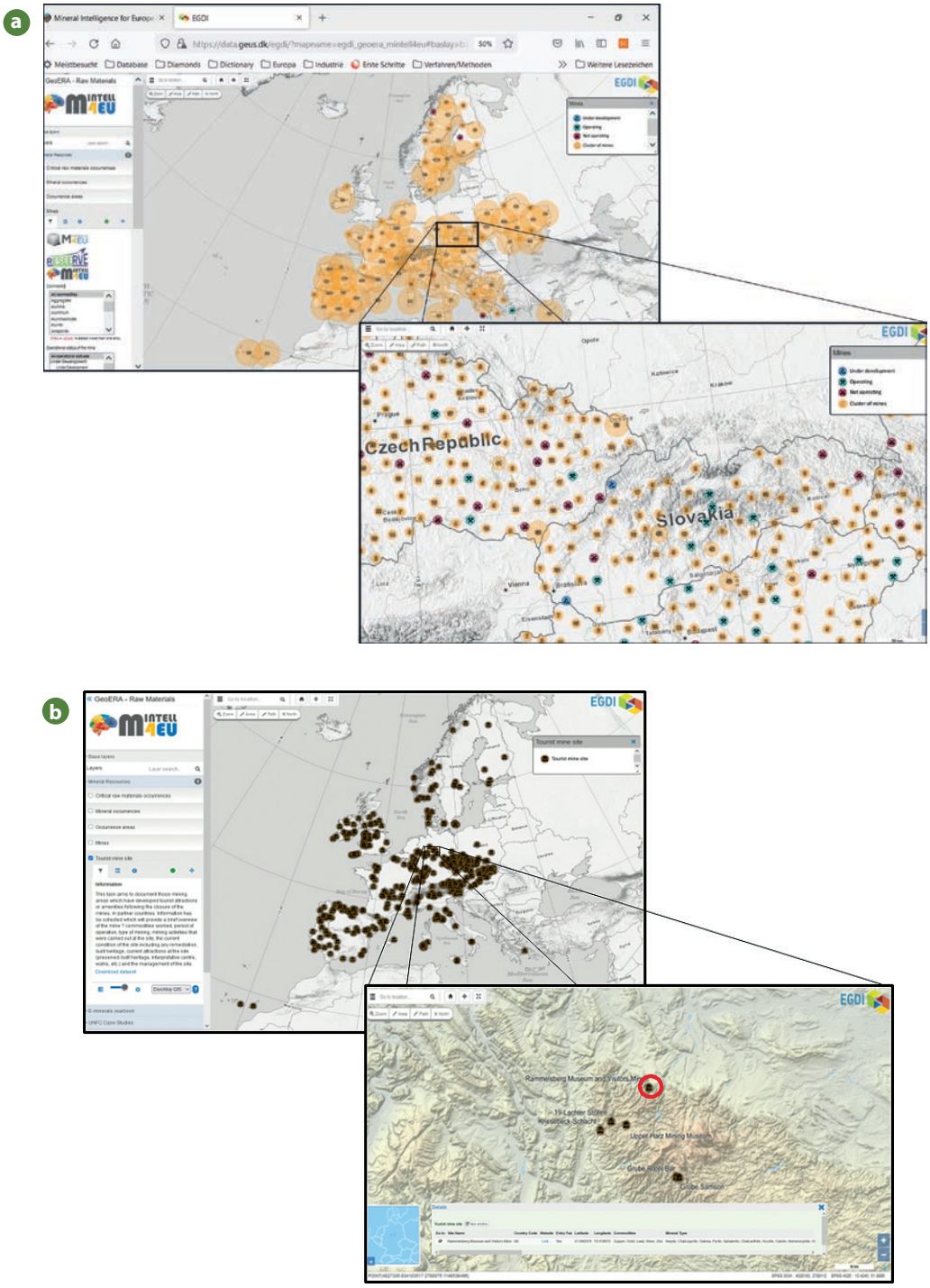

Figure 3.6 (a–b): *Mines layers can be displays as a general view of clustered groups; or as individual mine when zooming in, and when clicked at a mine, a light green box with more information appears (a); and Touristic Mine Sites (b). Ergänzung der Beschriftung um: More details can be explored in EGDI – https://data.geus.dk/egdi/?mapname=egdi_geoera_mintell4eu#baslay=baseMapGEUS&extent=-1591810,901180,7567380,5046670.*

Please note, when looking at the maps, that data availability and accessibility are still challenges to address in the future. Next, the maps only reflect what the data provider choose to share with MIN4EU, and the maps cannot represent all types of data in the database; thus the user is free to download the full database for further elaboration and explanations. Finally, if there is no data on a specific commodity in a country is not possible to identify whether this commodity is proven not to be present in that country or whether data are available but not shared for different reasons (typically confidentiality issues).

The options for combining data are numerous, and not only between the Mineral Resource theme and the e-MYB theme. An example of this is shown in Figure 3.7 where known gold deposits across Europe are displayed together with data on production (smelter in most cases) and import (no export data are available). The data behind the maps are massive and comprehensive, not all can be displaced in a map at once. Hence, further details are available in the underlying datasets including specification on type of production (e.g. mine, smelter/refinery).

However, the options do not end there as raw materials data can be combined with any other maps available in EGDI and might open new perspectives.

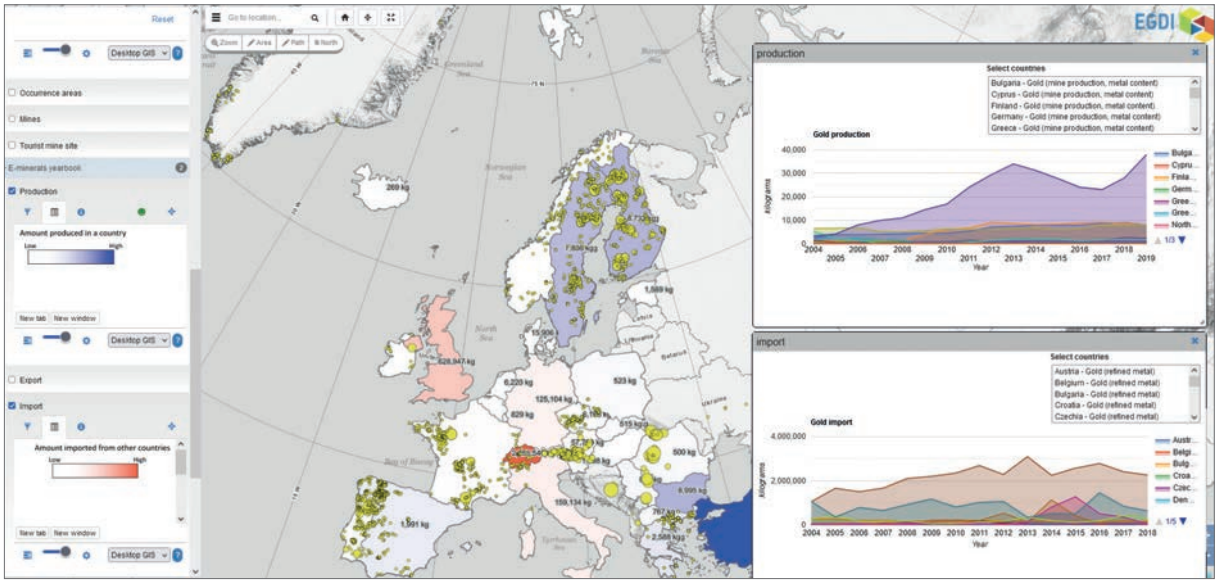

Figure 3.7: *An example of combined data: countries with gold production and imports as well as deposits across Europe. More details can be explored in EGDI – https://data.geus.dk/egdi/?mapname=egdi_geoera_mintell4eu#baslay=baseMapGEUS&extent=-1591810,901180,7567380,5046670.*

4 Outputs, recommendations and outreach

„Society needs resources – "leaving it in the ground is no option, but what's needed is a sustained framework for responsible resource management"
(Scott Foster, 19 January 2022 – Final Event)

This Chapter summarises some of the outputs and highlights of GeoERA. Several of the products were the first of their kind to be developed in Europe. The recommendations made by stakeholders during the Final Evaluation Meetings are outlined briefly, especially where they relate to the scientific content or where the outputs are expected to contribute to the future work of the 'raw materials community'.

First of their kind

- *Aggregated database (MIN4EU) with data on mineral occurrences and mines, production, trade, resources and reserves (MINTELL4EU project).*
- *Set of national atlases on ornamental stone (EUROLITHOS project).*
- *Compilation of mineral occurrences, geology and potential for specified critical raw materials, i.e., REE, lithium, cobalt graphite and phosphate (FRAME project).*
- *Pan-European maps on marine deposits (MINDeSEA project).*
- *Pan-European predictivity maps on marine and landlocked CRM (FRAME and MINDeSEA).*

An external reviewer stated: *"GeoERA has, without doubt, produced outstanding results. The user interface works well and the geodata are valuable and well presented. The project members are to be congratulated for these achievements especially so in the light of restrictions imposed by the Covid pandemic. The data now available to stakeholders represents a state-of-the-art snapshot of what is available. Ultimately, the quality, suitability and maintenance of the data are the responsibility of their custodians, for which GeoERA can have had only limited influence. However, the project has made great progress in harmonisation and quality control […]."*

An overview of the outreach activities within GeoERA Raw Materials projects will be presented while further details are given in the Annex.

The overview will be given in the following sections on a project-by-project basis starting with EuroLithos, continuing with FRAME, then MINDeSEA and finishing with MINTELL4EU.

4.1 EuroLithos - a pioneering project on Europe's natural stones

EuroLithos is a pioneering project on Europe's natural stone resources (Figure 4.1). It had to overcome major challenges in terms of standardization and harmonization of data and information. The lack of appropriate INSPIRE terminology required EuroLithos to develop innovative solutions to integrate EN standard terminology with INSPIRE by developing a project specific vocabulary. The longstanding tradition of using natural stone in a wide variety of applications (Figures 4.2 and Figure 4.4) has led to specific norms and standards that cannot currently be reconciled with INSPIRE. EuroLithos developed a data framework for ornamental stone for spatial and technical information (Carvalho and Heldal 2019; Heldal et al., 2019; Laskaridis and Heldal, 2021). EuroLithos has compiled 1,219 unique European ornamental stone sources in partner countries with basic data in geopackages in EGDI (Figure 4.3). So far, about 350 of these are linked to detailed reports. In addition, partner countries delivered national data on occurrences and mines to MIN4EU. However, harmonized terminology

Figure 4.1: *Limestone quarrying, Portugal. Photo courtesy Tom Heldal; source: EuroLithos-project.*

Figure 4.2: *Oslo opera house (2008) built from Italian Carrara marble. Photo courtesy Tom Heldal; source: EuroLithos-project.*

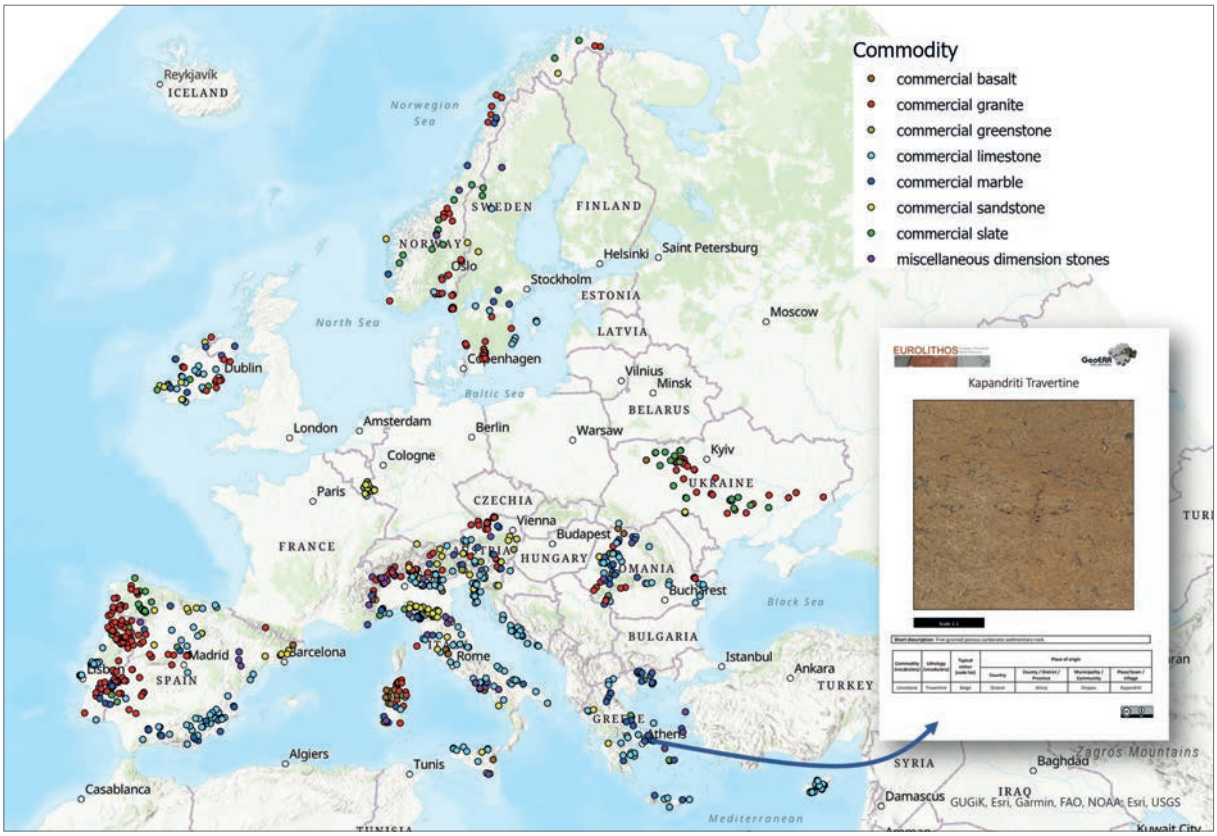

Figure 4.3: *Visualisation of atlases in maps; example of linking spatial information with standardised reports, EuroLithos.*

could not be resolved to our full satisfaction and should be further developed via the European Commission to the relevant and mandated working groups. EuroLithos made recommendations to overcome identified obstacles, tested the UNFC in the case of Larvikite, and shared the results with MINTELL4EU (Heldal and Fromreide Nesheim, 2021).

EuroLithos developed guidelines assessing the value of ornamental stone for society beyond its economic value (Heldal and Dedić, 2021). Case studies were carried out demonstrating best practice and underpin the final guidelines for assessing the cultural value of ornamental stone resources on a local, regional, and national scale (Dedić et al., 2020). Atlases of ornamental stone resources were produced for Cyprus, Greece, Italy (as a whole and the Italian region of Emilia Romagna in particular), Norway, Portugal and Slovenia. These are stored in the EGDI repository (Table 4.1). These atlases provide comprehensive information on the geology, ornamental stone deposits, their production, use, and heritage value in and for each country (Carvalho et al., 2020). Petrographic and physico-chemical properties are provided for each ornamental stone deposit. Missing data (e.g. some geochemical information) will be updated at a later stage.

A scientific volume has been submitted for publication in a future dedicated volume of the NGU Bulletin (https://www.ngu.no/side/ngu-bulletin). The publication will be online with free access.

EuroLithos external reviewer comment: *"The deliverables are really useful, a very good work instruction existing, primarily national, information and making it searchable on a broader, European level. The information compiled by the project also have a high potential in attracting interest to the natural stone area by several stakeholder groups such as students, geologists, geological surveys in general land use planers and local authorities, heritage authorities and politicians. It highlights the importance of natural stones through the ages, not only in ancient times but also in modern time."*

Table 4.1: List of EuroLithos national and one regional (Emilia Romagna) atlases and access details.

Country/region	Link
Cyprus	https://repository.europe-geology.eu/egdidocs/eurolithos/eurolithos+atlas_cyprus.pdf
Greece	https://repository.europe-geology.eu/egdidocs/eurolithos/eurolithos+atlas_greece_final.pdf
Italy (introductory part)	https://repository.europe-geology.eu/egdidocs/eurolithos/eurolithos+atlas_italy.pdf
Italy (Emilia-Romagna / regional)	https://repository.europe-geology.eu/egdidocs/eurolithos/eurolithos+atlas_emrom.pdf
Norway	https://repository.europe-geology.eu/egdidocs/eurolithos/eurolithos+atlas+norway.pdf
Portugal	https://repository.europe-geology.eu/egdidocs/eurolithos/eurolithos+atlas+portugal.pdf
Slovenia	https://repository.europe-geology.eu/egdidocs/eurolithos/eurolithos+country+atlas_slovenia.pdf

4.1.1 Recommendations to EuroLithos from Stakeholders

Stakeholders acknowledge and welcome the fundamental work and useful information provided by EuroLithos. Stakeholders made the following observations and recommendations:

- The main interested parties were not engaged to a large extent in the project, e.g. the stone industries, stone federations, the cities/municipalities (as one of the most important group of buyers of natural stone). For example, Europe's natural stone industry (e.g. EUROROC – https://www.euroroc.net/); the International Union of Geological Science (IUGS) initiative on Heritage Stones (http://globalheritagestone.com/) and its national activities. Therefore, future work would benefit from stronger bonds to a wider stakeholder group and more communication outside the project team is recommended.
- The term 'ornamental stone' is limiting and it is suggested that 'natural stones' be used instead following European standardization, e.g. CEN / TC 246 'natural stones'.
- Although EuroLithos is mindful of the sustainability and durability of natural stone, unbiased science-based Life Cycle Analysis (LCA) and Environmental Product Declaration (EPD) studies are needed to underpin these properties of natural stone.

The stakeholders urge EuroLithos "*to continue the work and include more natural stone types, more countries and initiate a closer collaboration with stakeholders outside the geological surveys[…].* "

Overall, stakeholders very much welcome EuroLithos committing to regularly upgrades and the publication of project results for at least the next five years, and welcome the invitation to other countries to participate in the project using the same data infrastructure.

***Figure 4.4:** Temple from Antiquity, Athens, Pentelli marble, see also Figure 2.2. Photo courtesy Tom Heldal; source: EuroLithos-project.*

4.2 FRAME - a stepping stone towards resilient raw materials value chains in Europe

The EU have deemed critical raw materials as crucial for the economy and takes securing a sustainable supply of raw materials as a key priority for the EU (European Commission, without a date). Access to strategic and CRM is essential to industrial and social development and the wellbeing of Europe (see Chapter 2). The EC has sponsored several networking activities and many scientific projects and pilot studies have received funds. However, the first step in the value chain - exploration – hardly takes place in Europe (Farooki et al., 2018). Exploration spending in Europe accounts for less than 5 % of global exploration investment and is also the lowest at international level since the early 1990s (RMG Consulting, 2021 and Figure 4.5).

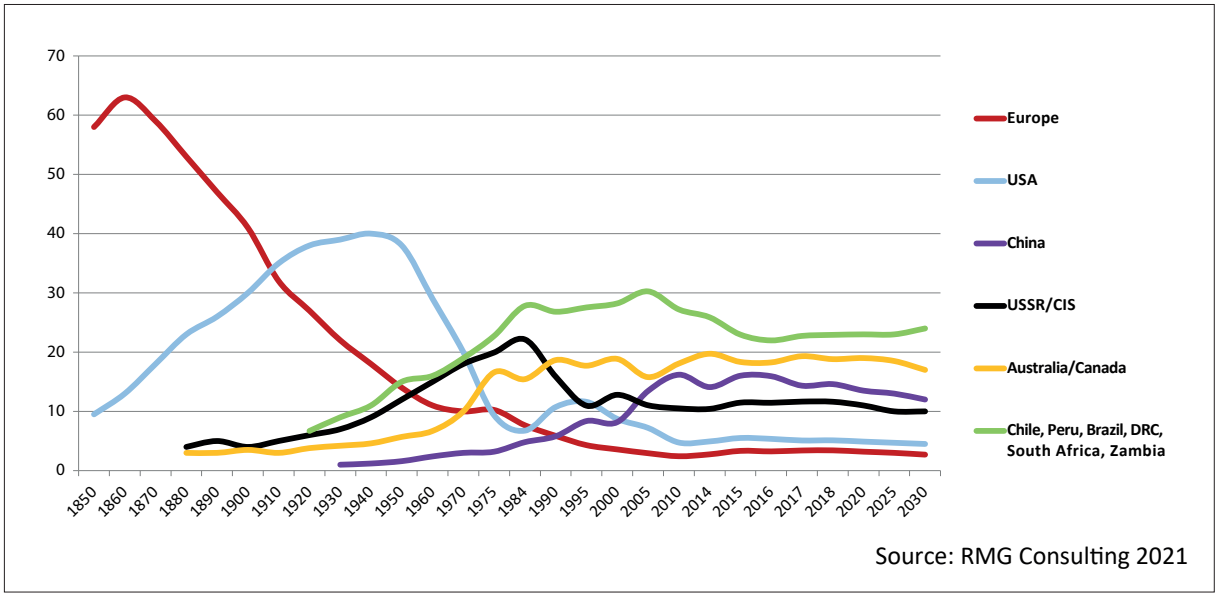

Figure 4.5: *Exploration expenditures expressed as percentage of world mining share starting in the year of 1850; source RMG Consulting, 2021, their figure 1.*

The geological conditions in Europe exist for the formation of economic ore deposits and if found and developed would add to primary the supply of several CRM. FRAME has highlighted the regions with the greatest potential within the respective project boundaries for selected raw materials using both old and new data (e.g. Sadeghi et al., 2020a; Gautneb et al., 2019; Gautneb et al., 2021). Compiling and publishing Pan-European metallogenic maps for the various areas while unlocking old data is an innovative aspect for many GSO. In addition, the close cooperation with MINDeSEA permitted the integration of both onshore and offshore prospectivity mapping for the first time in Europe. In this way, targets for exploration investment with were identified supported by detailed metallogenic studies (e.g. Decree et al. 2020; GSB et al.,2020 2021a; Reginiussen et al., 2021). FRAME has used high-resolution analytical techniques to explore strategic and critical raw materials as an essential part of targeting resources (e.g. GSB et al., 2021b). The (high-resolution) mapping of the distribution of chemical elements in an ore can be used, for example, to develop general models, insitu evacuation techniques or to improve beneficiation methods (Figure 4.6).

FRAME has developed methods for the improvement of the database of pan-European critical minerals deposits and mineral-based waste accumulations. These have been added to the European Raw Materials Knowledge Base (EURMKB). The work has been endorsed by peer-reviewed publications (Table 4.2). The Project looks beyond the established CRM list to other commodities taking into account the mineral expertise present in the project consortium and member states (e.g. Sadeghi et al., 2020b; Peireira and Quental, 2021; Sievers, 2021). Right

from the outset, FRAME has worked closely with the European Commission, as DG GROW requested easily accessible and reliable up-to date information on raw materials. FRAME made strenuous efforts to respond to the requests from the European Commission.

FRAME external reviewer comment: FRAME is a *"very successful project, forms a fantastic foundation layer for further development, with a lot of data usage potential"*. The data platform is a significant addition to our knowledge base with a digital metallogenic map highlighting the endowment and exploration potential of CRM in Europe.

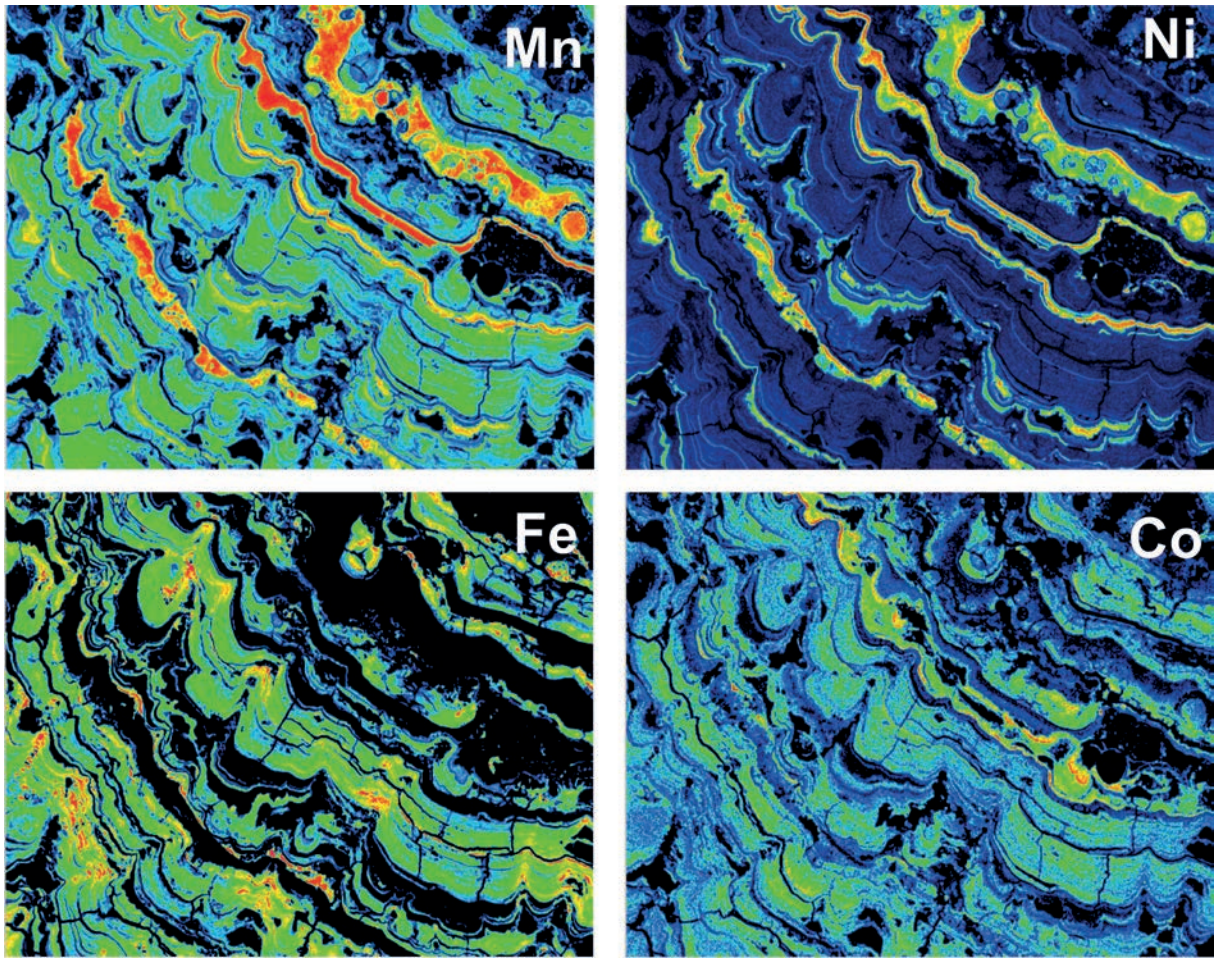

Figure 4.6: *EPMA high-resolution elemental mapping on a Fe-Mn crust. The strategic and critical elements are concentrated in different diagenetic or hydrogenetic layers. The colour code indicates the relative concentration of a chemical element; reddish colours indicate high concentrations, blue colours low concentrations. Modified from Marino et al., 2019; source MINDeSEA project.*

Table 4.2: *List of peer-reviewed papers by published by the FRAME project team.*

Author(s)	Year	Title	Journal	ISSN/ URL / DOI
Decrée S, Savolainen M, Mercadier J, Debaille V, Höhn S, Frimmel H, Bael JM	*2020*	*Geochemical and spectroscopic investigation of apatite in the Siilinjärvi carbonatite complex: Keys to understanding apatite forming processes and assessing potential for rare earth elements*	*Applied Geochemistry, 2020, 123*	https://doi.org/10.1016/j.pgeochem.2020.104778
Dehain Q, Tijsselin LT, Glas HJ, Törmäne T, Butche AR	*2021*	*Geometallurgy of cobalt ores: A review*	*Minerals engineering 2021, 160*	https://doi.org/10.1016/j.mineng.2020.106656
Girta M, Wittenberg A, Grill ML, de Oliveira DPS, Giosu C, Ruello ML	*2021*	*The Critical Raw Materials Issue between Scarcity, Supply Risk, and Unique Properties.*	*Materials 2021, 14, 1826*	https://doi.org/10.3390/ma14081826
Junge M, Kolb AC, Wittenberg A, Sievers H, Gega D, Onuzi K	*2021*	*Mineralogical characterization of podiform chromitite deposits in the Eastern Mirdita Ophiolite, Albania*	*ZDGG, 172 (1) 1-17*	DOI: https://doi.org/10.1127/zdgg/2021/0266
Małek R, Mikulski SZ	*2021*	*A rare indium-bearing mineral (Zn-In-Cu-Fe sulphide) from the Stara Kamienica Schist Belt (Sudetes, SW Poland).*	*Geological Quarterly 2021, 65(1), 7: 2*	https://gq.pgi.gov.pl/article/view/28487/pdf
Mikulski SZ, Małek R	*2019*	*Indium and other critical elements enrichment in cassiterite-sulphide Mineralization from the stratiform tin deposits in the West Sudetes (SW Poland). Life with Ore Deposits on Earth*	*15th SGA Biennial Meeting, 27-30 August 2019, Glasgow, Scotland, 4, 1818-1822*	https://e-sga.org/nc/publications/sga-biennial-meetings-abstract-volumes/2019-glasgow/
Mikulski SZ, Oszczepalski S, Sadłowska K, Chmielewski A, Małek R	*2020*	*Trace Element Distributions in the Zn-Pb (Mississippi Valley-Type) and Cu-Ag (Kupferschiefer) Sediment-Hosted Deposits in Poland*	*Minerals 2020, 10(1), 75*	https://doi.org/10.3390/min10010075
Mikulski SZ, Sadłowska K	*2019*	*The critical elements (V, Co, Ga, Sc, REE) enrichment of Fe-Ti-V oxide deposits related to Mesoproterozoic AMCG complex in Poland. Life with Ore Deposits on Earth*	*15th SGA Biennial Meeting, 27-30 August 2019, Glasgow, Scotland, 4, 1814-1817*	https://e-sga.org/nc/publications/sga-biennial-meetings-abstract-volumes/2019-glasgow/
Teran K	*2019*	*Critcal Raw Materials (CRM) in Slovenia.*	*Bulletin of Mineral Resources in Slovenia, GeoZS, 2019*	https://www.geo-zs.si/index.php/en/products/publications2/periodicals/mineral-resources

4.2.1 Recommendations to FRAME from Stakeholders

FRAME has combined different CRM datasets within its various work-packages and assesses, evaluates and interprets these in terms of ore genesis and prospectivity. Evaluation of the prospective areas and deposits according to an evaluation matrix have yet to be carried out. According to one stakeholder, the interactive map tool will be very useful for the engaged public. It was noted that in the Fraser Institute annual survey of mining companies Finland and Ireland frequently rank high on the mining investment attractiveness index.

Observations and recommendation from stakeholders included:

- The possibilities of using Artificial Intelligence (AI) for the harvesting of non-harmonized data should be investigated in order to focus the research agenda.
- Europe's raw materials potential should be highlighted.
- Further layers of information should be added to the database that are useful for the mining industry as well as policy makers and the public. For example: data on geophysics, ground and satellite derived geochemistry, land use (such as national park areas), cadastral information (licence availability etc.), cultural information (such as infrastructures, road and rail networks), legislative / tax and environmental controls.
- The project and databases need to be maintained after the project is completed so that the content remains live and up-to-date.
- More attention should be given to the long term use and dissemination of information from science to industry, policy makers and the public

Stakeholders reviewed FRAME as *"an impressive piece of work that moves towards meeting important national and trans-national goals, but which must now be built on and developed in imaginative ways. It is hoped that the European Commission will show vision and flexibility so to do, in partnership with the public bodies such as the European geological surveys but also with the global mining sector, the investors therein, and the various other stakeholders such as environmental groups."*

4.3 MINDeSEA - a Pathfinder project for Seabed Mineral Deposits in European Seas

MINDeSEA was designed to the compile, characterize, and map the different types of seabed deposits focussing on strategic metals and critical raw materials within European seas. The project developed pan-European maps of marine deposits, which are believed to be the first of their kind. The pan-European map of the energy critical elements Co and Li within seabed ferromanganese deposits is an example of this pioneer work. Close cooperation with FRAME facilitated linking to onshore CRM for the first time in Europe. This resulted in the first set of pan-European predictive maps on offshore and onshore CRM. The work on metallogeny and predictive maps (Schiellerup et al., 2021a; González et al., 2021a; Zananiri, 2021a; Ferreira et al., 2021a) underpin that potential. This will further enhance future exploration efforts as well as adding to scientific knowledge and support conservation of biodiversity(e.g. Schiellerup et al., 2021b; González et al.,2021a; Ferreira et al., 2021b; Somoza et al., 2021a).

***Figure** 4.7: Crosscut section of thick Fe-Mn crust from the Canary Islands Seamount Province. Modified from Marino, 2020; source MINDeSEA project.*

During the project information, at the Member State level, on marine legislation, information on activities (González et al., 2021c; Zananiri, 2021b; Somoza et al. ,2021b), case histories (such as technologies and observations in the biosphere) and recommendations developed as part of MINDeSEA were compiles. These are important in order to optimise resource management. ISA welcomed the work carried out by MINDeSEA in this regard (Figure 4.7).

MINDeSEA compiled much information, which was underpinned by scientific research in the course of the project. The scientific outcome is shared in several publications in high-ranking journals and also in a Special Issue of 2020 edited by Somoza and González (Table 4.3). The data cover basic scientific data (e.g. bathymetric, structural, mineralogical, geochemical) from a diversity of seabed deposit-types ranging from massive sulphide deposits, though polymetallic nodules and crusts to phosphorites and marine placer deposits (Figure 4.7).

Table 4.3: *List of peer-reviewed papers by MINDeSEA.*

Author(s)	Year	Title	Journal	ISSN / URL / DOI
Alcorn T, Monteys X, Blasco I, Lobato A, González J	*2021*	*Are the pan-European seas a promising source for critical metals supply? GeoERA-MINDeSEA Marine Data and Information Management Best Practices.*	*Bollettino di Geofisica Teorica ed Applicata 62*	https://imdis.seadatanet.org/content/download/151922/file/IMDIS2021_proceedings.pdf
Blokhin M, Zarubina N, Mikhailik P, Elovskiy E, Ivanova Y, González FJ, Somoza L	*2020*	*Discriminating formation and accumulation processes of some strategic metals in Fe-Mn deposits of the Atlantic Ocean.*	*World Journal of Engineering*	https://doi.org/10.1108/WJE-10-2020-0526
González FJ, Medialdea T, Schiellerup H, Zananiri I, Ferreira P, Somoza L, Monteys X, the MINDeSEA Team	*2020*	*Are the pan-European seas a promising source for critical metals supply? The project GeoERA-MINDeSEA.*	*European Geologist Journal, 49, 37-41*	https://eurogeologists.eu/gonzales-are-the-pan-european-seas-a-promising-source-for-critical-metals-supply-the-project-geoera-mindesea/
González FJ, Rincón-Tomás B, Somoza L, Santofimia E, Medialdea T, Madureira P, LópezPamo E, Hein JR, Marino E, de Ignacio C, Reyes J, Hoppert M, Reitner J	*2020*	*Low-temperature shallow-water hydrothermal vent mineralization following the recent submarine eruption of Tagoro volcano (El Hierro Canary Islands).*	*Marine Geology, 430*	https://doi.org/10.1016/j.margeo.2020.106333
González FJ, Somoza L, Medialdea T, Marino E, Blasco I, Lobato A, GeoERA-MINDeSEA Project	*2021*	*GeoERA-MINDeSEA Project: Establishing the metallogenic context for seabed mineral deposits in the pan-European seas.*	*Geo-Temas, 18, 753*	*ISSN: 1576-5172.*
Kfouri LO, Millo C, de Lima AE, Silveira CS, Sant'Anna LG, Marino E, González FJ, Murton BJ	*2021*	*Growth of ferromanganese crusts on bioturbated soft substrate Tropic Seamount northeast Atlantic Ocean.*	*Deep Sea Research Part I: ceanographic Research Papers, 175, 103586*	https://doi.org/10.1016/j.dsr.2021.103586

Author(s)	Year	Title	Journal	ISSN / URL / DOI
Marino E, González FJ, Kuhn T, Madureira P, Wegorzewski AV, Mirao J, Medialdea T, Oeser M, Miguel C, Reyes J, Somoza L, Lunar R	2019	Hydrogenetic Diagenetic and Hydrothermal Processes Forming Ferromanganese Crusts in the Canary Islands Seamounts and their Influence in the Metal Recovery Rate with Hydrometallurgical Methods.	Minerals, 9, 439	https://doi.org/10.3390/min9070439
Marino E, González FJ, Lunar R, Reyes J, Medialdea T, Castillo-Carrión M, Bellido E, Somoza L	2018	High-Resolution Analysis of Critical Minerals and Elements in Fe–Mn Crusts from the Canary Island Seamount Province (Atlantic Ocean).	Minerals, 8, 285	https://doi.org/10.3390/min8070285
Rincón-Tomás B, Duda JP, Somoza L, González FJ, Schneider D, Medialdea T, Santofimia E, López-Pamo E, Madureira P, Hoppert M, Reitner J	2019	Cold-water corals and hydrocarbon-rich seepage in Pompeia Province (Gulf of Cádiz)–living on the edge	Biogeosciences, 16, 1607–1627	http://doi.org/10.5194/bg-16-1607-2019
Rincón-Tomás B, González FJ, Somoza L, Sauter K, Madureira P, Medialdea T, Carlsson J, Reitner J, Hoppert M	2020	Siboglinidae Tubes as an Additional Niche for Microbial Communities in the Gulf of Cádiz—A Microscopical Appraisal.	Microorganisms, 8 (3), 367	https://doi.org/10.3390/microorganisms8030367
Somoza L, González FJ (Special Issue Editors)	2020	Marine Geology and Minerals.	Minerals, 10	https://www.mdpi.com/journal/minerals/special_issues/marine_geology_minerals
Somoza L, Medialde T, González FJ, Calado A, Afonso A, Albuquerque M, Asensio-Ramos M, Bettencourt R, Blasco I, Candón JA, Carreiro-Silva M, Cid C, De Ignacio C, López-Pamo E, Machancoses S, Ramos B Ribeiro LP, Rincón-Tomás B, Santofimia E, Souto M, Tojeira I, Viegas C, Madureira P	2020	Multidisciplinary Scientific Cruise to the Northern Mid-Atlantic Ridge and Azores Archipelago.	Frontiers in Marine Sciences, 7, 568035	https://doi.org/10.3389/fmars.2020.568035
Somoza L, Medialdea T, González FJ, León R, Palomino D, Rengel J, Fernández-Salas LM, Vázquez JT	2019	Morphostructure of the Galicia continental margin and adjacent deep ocean floor: From hyperextended rifted to convergent margin styles.	Marine Geology, 407, 299-315	https://doi.org/10.1016/j.margeo.2018.11.011

Author(s)	Year	Title	Journal	ISSN / URL / DOI
Somoza L, Medialdea T, González FJ, Machancoses S, Candón JA, Cid C, Calado A, Afonso A, Pinto L, Blasco I, Albuquerque M, Asensio-Ramos M, Bettencourt R, De gnacio C, LópezPamo E, Ramos B, Rincón-Tomás B, Santofimia E, Souto M, Tojeira I, Viegas C, Madureira P	*2021*	*High-resolution multibeam bathymetry of the northern Mid-Atlantic Ridge at 45–46° N: the Moytirra hydrothermal field.*	*Journal of Maps, 17*	https://doi.org/10.1080/17445647.2021.1898485
Somoza L, Rueda JL, Sánchez-Guillamón O, Medialdea T, Rincón-Tomás B, González FJ, Vázquez JT	*2021*	*The Interactive Role of Hydrocarbon Seeps Hydrothermal Vents and Intermediate Antarctic/Mediterranean Water Masses on the Distribution of Some Vulnerable Deep-Sea Habitats in Mid Latitude NE Atlantic Ocean.*	*Oceans, 2 (2), 351-385*	https://doi.org/10.3390/oceans2020021
Terrinha P, Medialdea T, Batista L, Somoza L, Magalhães V, González FJ, Noiva J, Lobato A, Rosa M, Marino E, Brito P, Neres M, Ribeiro C	*2020*	*Integrated thematic geological mapping of the Atlantic Margin of Iberia.*	*Geological Society London, Special Publications, 505*	https://doi.org/10.1144/SP505-2019-90
Zalba I, González FJ, Fernández-Puga MC, Nyberg J	*2021*	*Ferromanganese concretions in the Baltic Sea: characterization and forming processes.*	*Geo-Temas, 18, 775-778*	*ISSN: 1576-5172*

As an important and reliable source of information, MINDeSEA contributed to three editions of the EU Blue Economy Report in 2019, 2020 and 2021 (European Commission, 2019b; 2020f; 2021d). The European Commission DG MARE has invited the consortium to continue its involvement to the EU Blue Economy Report (Viegas H, pers. comm., 23 Nov. 2021).

MINDeSEA Review comments: *"MINDeSEA demonstrates the European capability to establish facilities for storing seabed deposit data and guaranteeing their long-term stewardship and distribution. The database outcomes lead to critical refinements of our current understanding and knowledge of European deposits. These databases are a key factor to develop metallogenesis 4-dimensional models and for establishing a first European budget of the metal resources. The insights will allow to set up some of these deposits as natural laboratories for sustained time series observations needed to monitor the complex interplay between [sedimentary], magmatic, tectonic, hydrothermal, and biological processes to gain understanding into their [genesis] and economic potential. This work is also laying the foundation for targeting in the near future the most accessible resources to be mined with a minimum environmental impact. In addition, this project defines a new volume of the European digital scientific library for managing, indexing and providing access to ocean and marine derived data sets, acquired during cruises and by European institutions in European marine waters."*

„The achievements of the MINDeSEA project represent a remarkable milestone in terms of the pan European seabed mineral deposits knowledge base."

4.3.1 Recommendations to MINDeSEA from Stakeholders

The data and information collected are based on scientific cruises, and MINDeSEA compiled information of every scientific cruise recorded in Europe (Somoza et al., 2021a). However, exploration cruises are inherently limited (e.g., spatially, temporally, financially) and can only map a fraction of the over 15 million km^2 European marine area. Consequently, there are limits to how much the knowledge gained by the compiled information can be extrapolated across larger areas. Further work is needed to fully understand and develop the potential of Europe's seabed resources. Knowledge, technologies and logistical challenges overcome on marine exploration cruises can also help in the development of complex deposits on land. Examples range from the development of adapted processing methods for polymetallic ores from the sea (e.g. massive sulphides), which can increase the economic viability of complex deposits on land, to minimally invasive, remotely controlled or semi-automated machines for exploration and mining in inhospitable environments.

Stakeholders made the following observations and recommendation:

- Work compiling legislation and recommendation on the management of seabed minerals should be carried out jointly with the International Seabed Authority (ISA). Such work would benefit from interdisciplinary, transnational research teams. ISA recognises MINDeSEA as an important source of information regarding environmental issues (Schwarz-Schampera U, pers. com. 20. Jan. 2022). ISA welcomes further involvement especially while ISA prepares the mining law for the seabed in international waters.
- Stakeholders highlighted the increasing importance of environmental aspects that should be described / studied in more detail in future projects and recommended the further development of the necessary expertise (e.g. systematic inventory of the associated fauna by biologists). ISA suggested that 50 percent of the work in the area should be focused on environmental issues.
- Stakeholders stressed the need to identify the main bottlenecks to using seabed mineral resources; that solutions to tackle those bottlenecks be identified; and to ensure (fruitful) interactions with NGOs.

Suggestions for further steps are mentioned by ISA (Figure 4.8 and Section 4.6).

Figure 4.8: *User perspective on MINDeSEA: comments by ISA presented at the Session on "Impacts on policy goals and response to expectations" GeoERA Final Event, 20 January 2020.*

A stakeholder reviewer of MINDeSEA stated *"Gaining more knowledge on inactive hydrothermal deposits is of crucial importance for lowering the environmental impact of future deep-sea mining."*

4.4 MINTELL4EU – the core project for a reliable European mineral database of raw materials

MINTELL4EU was designed to improve the EURMKB by updating the **electronic Minerals Yearbook (e-MYB)**, by extending the spatial coverage and quality of data currently in the **Minerals Inventory** and by increasing the degree of harmonization, communication and interaction between existing data platforms.

Working closely with the three other GeoERA Raw Materials projects as well as with the GeoERA Information Platform project, and on the foundations of previous projects, the project updated and upgraded the minerals intelligence database for Europe (MIN4EU). The spatial coverage with data has been expanded and for the first time, resource data from western Balkan and one Germany State occur in the database and on the European map. These INSPIRE complaint data are supported by 36 data providers covering 31 countries. Over 60,000 records for mining sites are included and the historical mine sites in the database has a touristic component. However, data quality and harmonization is a perpetual challenge. Training, workshops and the development of quality assurance tools were used to achieve improvements in the databases. Future projects and new data providers may benefit from technical reports, guidelines, templates and workflows. An automated data harvesting methodology collects data (mineral occurrences and mines) currently from 36 providers allowing newcomers a smooth integration. The harvesting system has an error detection tool to check and ensure the quality of data (Bahar et al., 2021).

Standardisation efforts achieved a common understanding of the INSPIRE-compliant code lists (Esser et al., 2021). Those efforts included also testing the use of the UNFC (United Nations Framework Classification of Resources) system on European mineral resource data by implementing recommendations from the ORAMA project. Nineteen case studies from nine countries have been completed across a number of different commodities and scales throughout Europe (Simoni et al., 2021) resulting in a compilation of challenges encountered and a listing of further recommendations (Hokka et al., 2021). For the first time, a data visualization tool for presenting the UNFC-compliant project information in a graphical manner was drafted. The test cases have drawn quite some attention in the UNECE. The most relevant guidance documents and reports are listed in Table 4.4.

The e-MYB was updated up to 2019, covering data from 40 counties on production and trade as well as data on resources and reserve from 17 counties. Data on up to 60 commodities and exploration data from seven countries were included in the yearbook. The pilot testing of UNFC encouraged eight partners to provide their resource and reserve data using the UNFC codes.

The e-MYB, the Minerals Inventory and the MIN4EU-database are united within one comprehensive platform to facilitate automation and sustainability enabling appropriate and streamlined interfaces for EGDI end users. The database provided is the most reliable, up-to-date, freely available mineral information database in Europe. All data is available under Creative Commons licenses. It is visualised at a user-friendly portal, providing vital information to governmental and private stakeholders, for planning and investment purposes. The information is available through the EGDI platform and shared with RMIS, and testing to share with EPOS (European Plate Observing System) has also been carried out. The system is built with open-source technology, making its long-term sustainability easier. The data will not face commercial lock-in issues in the future, an issue that plagues commercial systems. The upgrading of the database is planned within further projects aimed at developing a Geological Service for Europe while harvesting in the period between projects is also assured.

MINTELL4EU Reviewer commented MINTELL4EU *"forms a good foundation with easy access to useful and reliable mineral intelligence / data for the whole of Europe."*

"This project has demonstrated that a new geo-vision could be possible for Europe."

Table 4.4: *Selection of most relevant guidance documents and reports by MINTELL4EU.*

Author(s)	Year	Title	Journal	ISSN/ URL / DOI
Bahar B, Kumelj Š, Vihtelič A	*2021*	*Quality control system for harvesting report.*	*MINTELL4EU Deliverable D3.3*	https://geoera.eu/wp-content/uploads/2021/10/D3.3-Quality-control-system-for-harvesting-report.pdf
Deady E, Kumelj Š, Idoine N, Passmore J, Brown T	*2021*	*Report describing the processes developed for updating the electronic European Minerals Yearbook.*	*MINTELL4EU Deliverable D2.1*	https://geoera.eu/wp-content/uploads/2021/11/D2.1-Electronic-European-Minerals-Yearbook.pdf
Hokka J, Eilu P, Schjøth F, Aasly K, A	*2021*	*Report on harmonization issues, data gaps and challenges, reviewing also the quality of Pan-European aggregated inventories for selected commodities.*	*MINTELL4EU Deliverable D4.2*	https://geoera.eu/wp-content/uploads/2021/10/D4.2-UNFC-Harmonisation-issues-gaps-and-recommendations.pdf
Jørgensen LF, Deady E, Kumelj Š, Aasly KA, Urvois M, Pedersen M, Schjøth F, Tulstrup J	*2021*	*Project management report.*	*MINTELL4EU Deliverable D1.3 Final*	https://geoera.eu/wp-content/uploads/2021/11/D1.3-Final-Project-management-report.pdf
McGrath E, Workmann T	*2021*	*Historic tourist mines GIS*	*MINTELL4EU Deliverable D4.3*	https:// geoera.eu/wp-content/uploads/2021/11/D3.4-Tourist-mine-sites.pdf
Kumelj Š, Bahar B, Vihtelič A, Hribernik K, Schjøth F, Heijboer T, Whitehead D, Pedersen M	*2021*	*Minerals Inventory Report.*	*MINTELL4EU Deliverable D3.1 Final*	https://geoera.eu/wp-content/uploads/2021/11/D3.1-Mineral-Inventory-Report-Final.pdf
Simoni M, Aasly KA, Eilu P, Schjøth F,	*2021*	*Case study review with guidance and examples for applying the UNFC to European mineral resources.*	*MINTELL4EU Deliverable D4.1*	https://repository.europe-geology.eu/egdidocs/mintell4eu/d41-mintell4eu-case-study-overview-final.pdf

4.4.1 Recommendations to MINTELL4EU from Stakeholders

The EU considers pan-European information on the location and spatial distribution of primary and secondary raw materials as being of vital importance for decision makers in the fields of raw material supply security, environmental management and resource efficiency. This requires up-to-date and reliable data, and is the principal reason why efforts such as those of MINTELL4EU should be sustained. Future projects should take advantage of the identified opportunities as well as the obstacles and bottlenecks in data acquisition and harmonization procedures that need to be addressed in future activities (Jørgensen et al., 2021).

Stakeholders made the following observations and recommendations:

- "The development of a quality control system for harvesting reports and of a GIS database layer, illustrating relevant historic mine features, was an important aspect complementing the data display."
- The system should be expanded to include features such as designing maps targeting the interest of specific stakeholder groups such as hard rock aggregates, sand aggregates, industrial minerals, and cement

industries. The visualisation of data in the EGDI portal will allow assessment, evaluation and interpretation of genetic and prospectivity aspects of such commodities. This is a longstanding requirement with the potential for more studies of that kind.

- A full pan-European coverage is a recurring request by DG GROW, and stakeholders recommend that the remaining 15 German regional surveys share their raw material data with MIN4EU in order to complete the mid-European part of the dataset in the near future. The data gaps from a number of EU Member States remain (Bulgaria, Estonia, Latvia, Lithuania, and Malta) and require targeted attention.

4.5 Outreach

GeoERA was conceived as a pan-European network, to improve the knowledge and database on raw materials in Europe. Many efforts have been made to actively engage with specific stakeholders such as policy makers, industry and other interested parties, as well as the geoscientific community and other scientists in order to target and disseminate results according to user needs. The European Commission - DG GROW has acted as a key stakeholder. At their request, regular meetings were held to provide them with timely information on current and new data related to their work. MINDeSEA provided an important contribution to three editions of the EU Blue Economy Report and the MINDeSEA team has been invited by the European Commission to contribute further beyond the lifetime of the project.

The enormous dissemination and communication output by MINDeSEA and FRAME, in particular, is a strong endorsement of the entire GeoERA Team.

In addition to presentations at national and international conferences, exhibitions and trade fairs, newsletters and press releases, social media, many peer reviewed journal articles were published. During the project, two colleagues completed their doctoral theses in connection with the FRAME and MINDeSEA projects. As well as the 16 GeoERA newsletters, one of which was dedicated to raw materials, individual project (FRAME, EUROLITHOS and MINDeSEA) newsletters were published and reached audiences of from 100 to 150 each. There was also significant interest in GeoERA raw materials conferences (Annex Table A 2). GeoERA RM expected to publish a total of 10 peer-reviewed articles during the project period. This was exceeded by GeoERA raw material projects with more than 20 articles already published (Radej et al., 2022 , Figure 4.9). The list of peer-reviewed papers is shown in Table 4.2 and Table 4.3. The full compilation the outputs of scientific relevance are provided in Tabels A 1; A2; A3 of the Annex.

Affected by the COVID-19 pandemic, the GeoERA commodity team looked for alternatives to reach the public. A new format called 'did you know' (DYK) was created and debuted on https://geoera.eu/themes/raw-materials/ in summer 2019. More than 65 DYK on products, conferences and curiosities around strategic and critical commodities were highlighted. Some examples are shown in Figure 4.9.

The remarkable outreach activities are recognised as exceptional by eternal evaluators and the internal monitoring team (Figure 4.10).

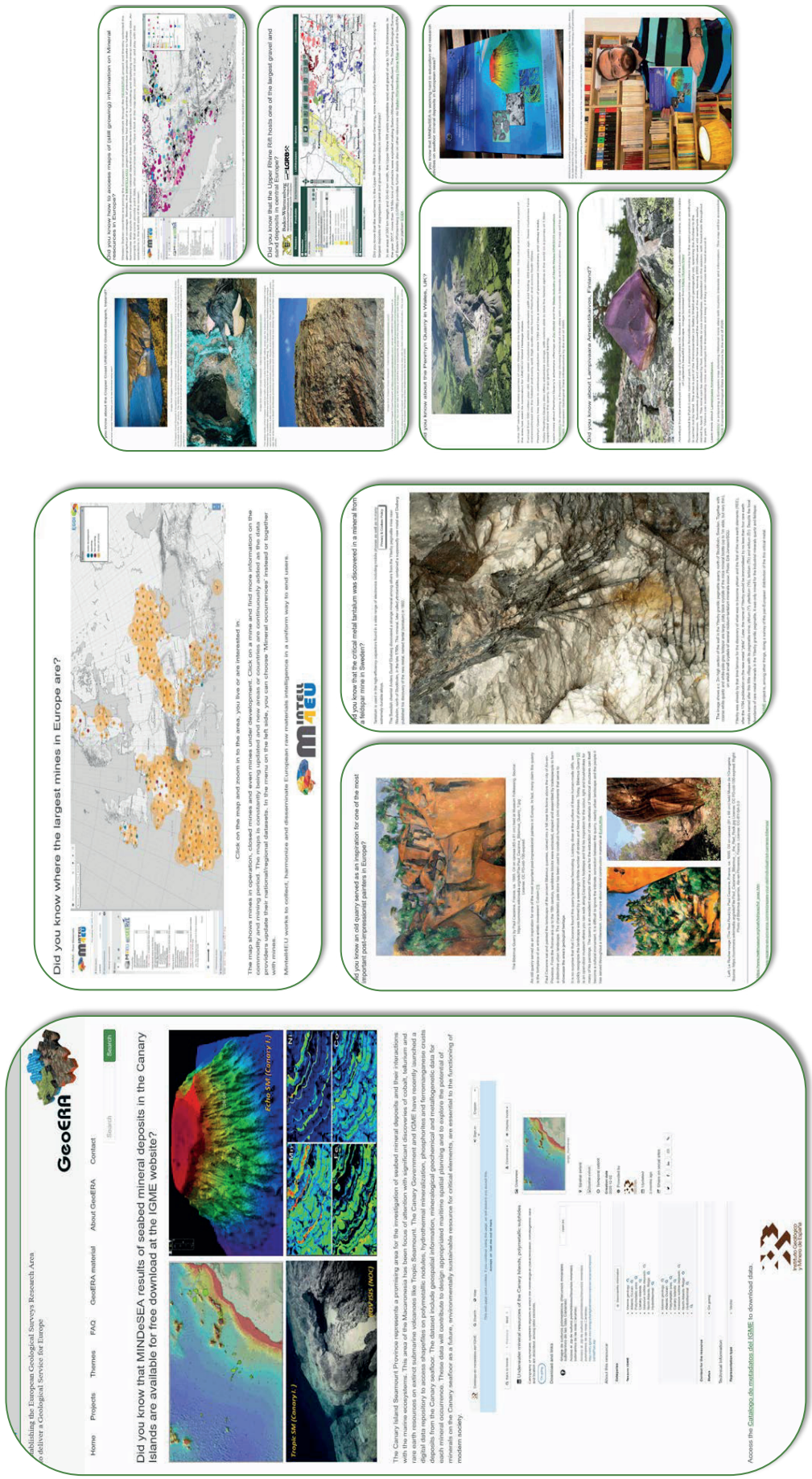

Figure 4.9: *Top 10 examples of DYKs for which between 3651 and 1828 views were counted, further examples accessible on* https://geoera.eu/themes/raw-materials/ *and @GeoERA_DidUKnow.*

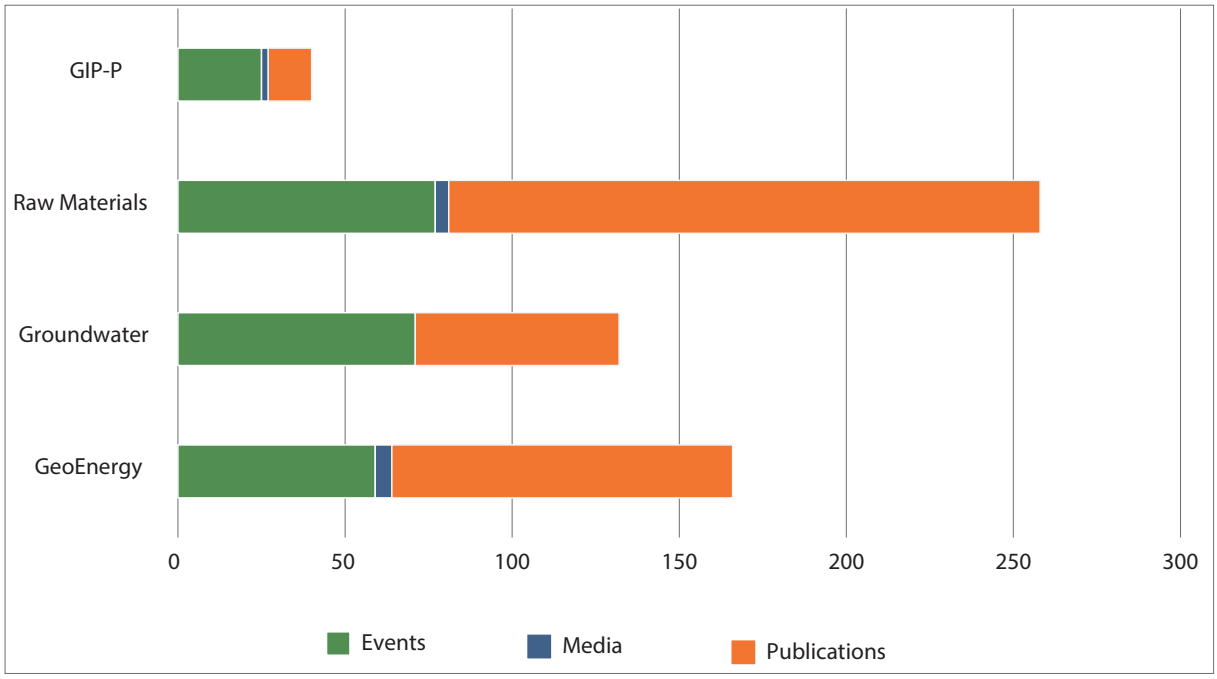

Figure 4.10: *Dissimination and communication activities per GeoERA theme, see Appendix III Table 16 of Radej et al., 2022.*

4.6 Final comments and recommendations

During the final GeoERA conference in January 2022, external evaluators and stakeholders commented on GeoERA Raw Materials, discussed further requirements and provided suggestions and recommendations (see https://geoera.eu/presentations/). Some of those were:

- *„Europe is nowadays highly dependent on raw material imports. Is Europe just under-explored, especially in crustal parts below few hundred meters, is it a matter of access to mineral deposits, a lack of capital for exploration, is it overregulated or do all these facts contribute to the lack of Europe's supply base? Certainly continuation and improving further the minerals inventory of Europe is required".* Robert Holnsteiner, Head of Directorate „Mineral Resources Policy, BMLRT / AT; Figure 4.11);
- MINDeSEA is an important project for ISA, "*it contributes to the best possible, knowledge-based regulation for future marine mining. Marine resource assessments are required to meet increasing global resource demands"* (Ulrich Schwarz-Schampera, Programme Management Officer at the ISA; Figure 4.12);
- *„Resilience & Autonomy key for EU prosperity – GeoERA data and maps are visualising mining potential in the EU and support EU economic recovery and growth"* (Rolf Kuby, Euromines Director General, Figure 4.13).

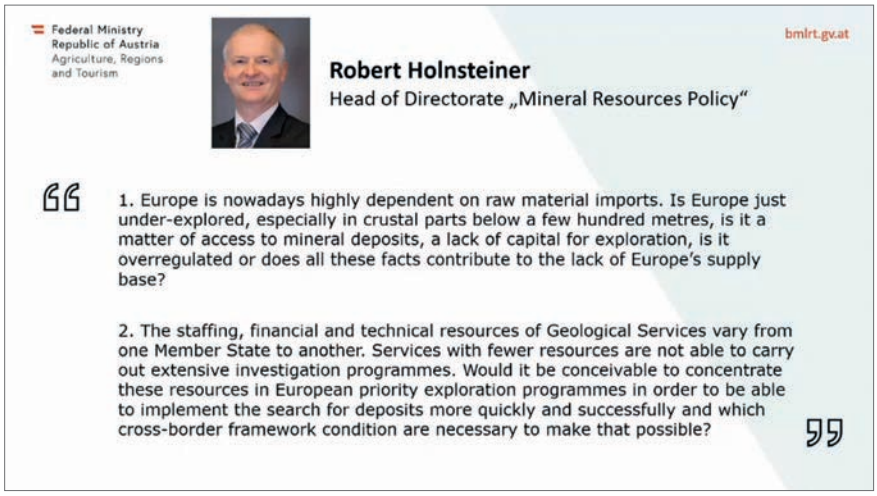

Figure 4.11: *Stakeholder statements by a Member State Authority at the GeoERA Final Event, January 2022.*

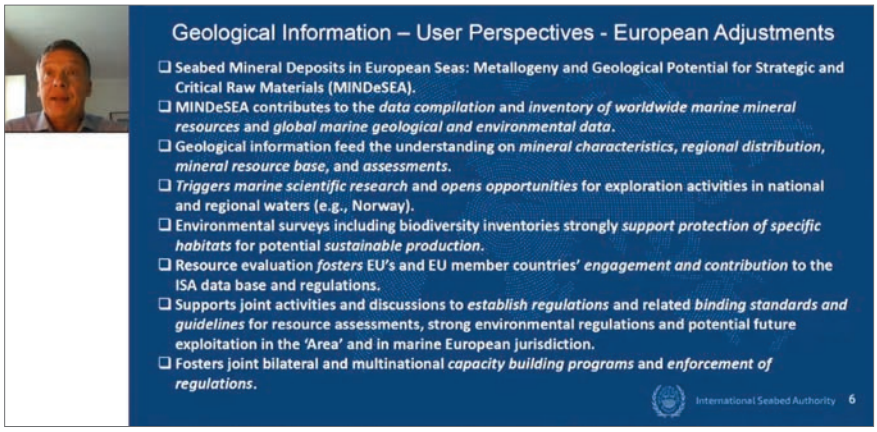

Figure 4.12: *Some stakeholder statements by an UN organisation at the GeoERA Final Event, January 2022.*

Figure 4.13: *Stakeholder statement by an industrial association at the GeoERA Final Event, January 2022.*

"The needs of geoscientific information in the future will be vastly different from the needs of the past. The future society will demand a holistic view of how geoscience connects to sustainable development. Geoscience information for the future should go beyond the traditional siloed, rigid, supply-driven database-oriented approaches to integrative knowledge solutions that are user-focused and transcends disciplines." (Comment by an external reviewer, December 2021)

The four GeoERA Raw Materials projects made great efforts to disseminate their products and findings (Section 4.5). Good communication with key stakeholders such as the European Commission (e.g., DG GROW, DG MARE, JRC), the UNECE, and European Industry and Research Networks has been acknowledged. The community is invited to keep contact with the GeoERA consortium and to provide input in the future (Figure 4.14). The EC acknowledged GeoERA Raw Materials as an important piece of work to assist the EU in achieving the EU GREEN DEAL, SDG (summarised by MINTELL4EU with the knowledge base supported by EUROLITHOS, FRAME and MINDeSEA). Peter Handley (DG GROW) noted that GeoERA Raw Materials has supported the European Commission's Action Plan on Raw Materials in all its 10 Actions to varying degrees (European Commission, 2020b). It was stressed that GSOs are needed to support strategic partnerships with third countries set-up in the course of the EC raw materials diplomacy (European Commission, without date). GSOs are already participating in many of these raw materials partnerships. Within GeoERA, the EU-Ukraine Raw Materials Partnership with GEOINFORM as a partner in all GeoERA projects, the EU-Canada Raw Materials Partnership with Natural Resources Canada (NRCan) as a member of the Stakeholder Council, and the EU-Latin America Raw Materials Partnership are implemented in particular through MINDeSEA and FRAME. The latter have also strengthened GSO's network in relations with these regions, as well as holding conferences, trainings and workshops.

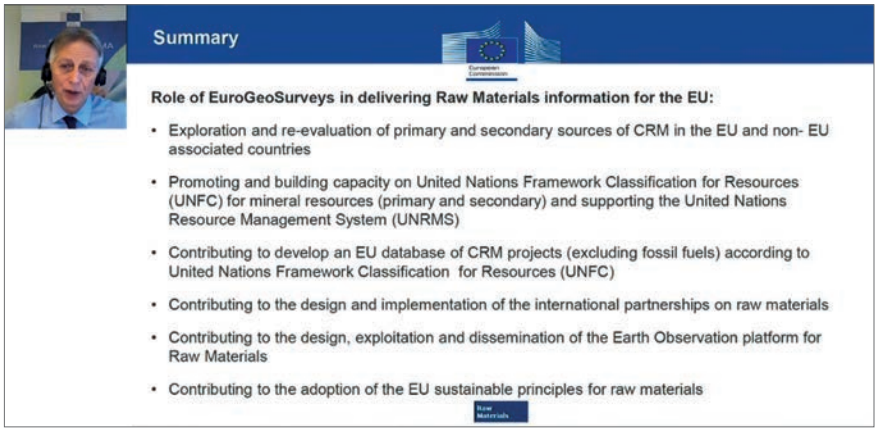

Figure 4.14: *The summary slide presented by Peter Handley, Head of Unit Energy-Intensive Industries and Raw Materials, DG GROW at the final event indicating future opportunities.*

The value and importance of the data compiled are highly appreciated and it is acknowledged that up-to-date information requires maintenance and new input. Furthermore, a Member State Ministry suggested to present the GeoERA Raw Materials findings at one of the next meetings of the RMSG.

However, despite the success of GeoERA Raw Materials, stakeholders see the need to:

- Build on the cascade of decision making from local level to European level to ensure acceptance;
- Acknowledge that the geopolitical situation in the world has changed, the dominance of China in supply of commodities is extreme and their way of acting is not always in line with the European sustainability principles;
- EU needs to support the development of domestic raw materials – and this message needs to be delivered to our politicians.
- The GSOs community (together with industry) needs to stand-up to ensure autonomy and resilience in the field of raw materials. We need to discuss (openly) the issues with all parts of society;
- Regulators need to be brought on board to support GSOs and to facilitate them gaining the necessary expertise and resources;
- Involve the European Committees (e.g. European Economic and Social Committee (EESC), European Committee of Regions (COR)), to get the political support for future work;

- Pool EU resources for upstream activities (Research and Innovation) to focus on frontier topics such as deep exploration onshore and marine minerals;
- Continue to concentrate on making EU geoscience data to support entrepreneurial activities taking into account the global competition for exploration funding; and
- Consult with data users to determine what data is needed, in what form, for what purpose and how it should be delivered.
- It is strongly recommended that GeoERA Raw Material reports, products, achievements and opportunities are communicated on a national and regional level to political and administrative decision makers. In particular economic, planning and environment ministries should be targeted, in order to facilitate sustainable and environmentally conscious mining projects. The Final Report on Impact Assessment includes the statement:
- [GeoERA] evaluators suggested the preparation of **specific guidelines** or policy documents for policymakers at national and EU levels. The output of projects like GeoERA is often scientific, and in order to reach a broader audience, information must be presented in a format targeted to that audience, often the general public.
- An important factor for the sustainability of GeoERA results is the **development of new services** that can be made available to scientists, policy makers and other stakeholders in a sufficient extent in the future.

A recurring recommendation from stakeholders is to use the results for promoting a shift of knowledge towards **citizen science**, including young scientists and scholars. Specifically, GeoERA has included the local dimension (e.g. public acceptance of mining, local tourism related to historical mine sites, local knowledge and education, such as 'geological paths'). It is agreed that greater emphasis should be placed on these matters in GeoERA Projects.

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6 Grant Information

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

7 Acknowledgments

The GeoERA Raw Materials community would like to thank the numerous colleagues of the national and regional GSO's in Europe that have supported and contributed at several stages to GeoERA. Their work conducted in previous national and trans-national projects are the foundations on which GeoERA Raw Materials has been built.

Special thanks are also addressed to the stakeholders (ministries and other authorities, R&I community, industry and entrepreneurs) that provided valid input to the pertinent issues that arose during GeoERA.

Last but not least, our thanks go to Gerry Stanley. His great support during the start-up phase as coordinator has helped to clearly define the project goals and has led to the success of GeoERA RM. His expertise and distance from the projects, which comes from his retirement, make Gerry the excellent reviewer for this monograph that he is.

Glossary

Glossary terms used by GeoERA Raw Materials and in line with the existing glossary hosted by JRCs RMIS.

BLUE Economy Report

The yearly EU Blue Economy Report is a publication by the European Commission (DG MARE) continues to analyse the scope and size of the Blue Economy in the European Union.

Classification system of mineral resources and reserves

A Classification System of resources and reserves is a scheme which allows the identification and recording of estimates of geological information (optionally with other parameters relevant for the intended audience and intended use of the information) each labelled to indicate 'essential characteristics' such as gradations of confidence in geological knowledge, technical and economic considerations, thus aiding decision making regarding the resources and reserves so described. (Working definition for the purposes of this study.)

All Reporting Standards and Reporting Codes include a system for the classification of mineral resources and reserves. Examples include the UNFC-2009 (United Nations Framework Classification), the PERC reporting standard 2013 (Pan-European Standard for Reporting of exploration results, mineral resources and reserves), the JORC code (the Australasian code for reporting of exploration results, mineral resources and ore reserves).

Construction minerals

Natural aggregates, recycled and manufactured aggregates, clays and gypsum, and building stone used for a wide range of construction purposes. These uses may be either directly as aggregates (e.g. sand and gravel) or in making cement, lime, concrete, plasterboard, bricks, asphalt mixes for surfacing roads and other building products. Natural aggregates include crushed rock of sedimentary, igneous and metamorphic origin.

CRIRSCO

Committee for Mineral Reserves International Reporting Code under the auspices of the Council of Mining and Metallurgical Institutes is a grouping of representatives of organisations that are responsible for developing mineral reporting codes and guidelines worldwide.

EEZ

The United Nations Convention on the Law of the Sea (UNCLOS) outlines the areas of national jurisdiction as a 12 nautical-mile territorial sea; an exclusive economic zone of up to 200 nautical miles and a continental shelf. The international seabed area – the part under ISA jurisdiction - is defined as "the seabed and ocean floor and the subsoil thereof, beyond the limits of national jurisdiction."

Electronic Minerals Yearbook

A part of the MIN4EU database containing both the Minerals Inventory and the electronic Minerals Yearbook (e-MYB).The e-MYB contains data on for production data from 2004 – 2019, and trade data from 2004 – 2018. It also contains resource, reserves and exploration data with a reference year of 2019 (and an older dataset with a reference year of 2011 – 2013).

Energy minerals

Non-renewable energy sources of both inorganic and organic origin in the earth's crust in solid, liquid and gaseous form.

They are used in the production of electricity, as fuel for transportation and for heating. Examples included coal, oil and natural gas.

EU Member States

Member countries of the European Union, currently comprising 27 countries. Since February 2020 these are: Austria (AT), Belgium (BE), Bulgaria (BG), Croatia (HR), Cyprus (CY), Czech Republic (CZ), Denmark (DK), Estonia (EE), Finland (FI), France (FR), Germany (DE), Greece (EL), Hungary (HU), Ireland (IE), Italy (IT), Latvia (LV), Lithuania (LT), Luxemburg (LU);Malta (MT); The Netherlands (NL); Poland (PT); Portugal (PT); Romania (RO); Slovakia (SK); Slovenia (SI); Spain (ES); Sweden (SE)

EU-level

Referring to overarching communal policies, systems or processes that are driven towards, embraced or adopted by - as a minimum - the EU Member States, and which may be adopted voluntarily by neighbouring or accession states.

Eurostat

Its task is to provide the European Union with statistics at European level that enable comparisons between countries and regions.

GeoPackage

GeoPackage is an open, standards-based, platform-independent, portable, self-describing, compact format for transferring geospatial information.

Industrial minerals

Industrial minerals – are minerals that are neither metallic nor energy related that are valued for their physical or chemical properties in a range of industrial applications.

'Physical' minerals include barite, bentonite, graphite, kaolin, diatomite, feldspar mica, silica, and talc, whilst 'chemical' minerals include fluorspar, potash, magnesite, salt and others. These appear in a range of industrial applications such as the manufacture of chemicals, glass, paints, plastics and paper. Industrial minerals include 'construction minerals' used for non-construction purposes, such as gypsum and limestone. For the purposes of this project, gemstones are included in this group.

INSPIRE

The INSPIRE Directive in Europe establishes an infrastructure for spatial information to support community environmental policies and policies or activities that may impact on the environment. The purpose of the INSPIRE Directive is to ensure that the spatial data infrastructures of the Member States are compatible and usable in a community and trans-boundary context.

JORC

Joint Ore Reserves Committee is a body managing the JORC Code, which is the Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves. JORC is a member of CRIRSCO, being the National Reporting Organisation for Australasia. Reports prepared in accordance with the JORC Code and issued with a certificate of consent from the Competent Persons who prepared them are accepted by all major international stock exchanges including those regulated by ESMA in Europe

Marine minerals

Minerals obtained from the marine environment.

Metadata

Information describing data sets and data services and making it possible to discover, inventory and use them.

Metalliferous minerals

Minerals or aggregates of minerals from which metal can be extracted.

Metals may be present either in their native form (e.g. gold, platinum), but more commonly as oxides, sulphides, sulphates, silicates etc. They include semi-metallic elements or metalloids (e.g. antimony, arsenic, germanium), which are frequently intimately associated with metals. For the purposes of this project, metalliferous minerals used for non-metallic purposes (e.g. ilmenite) and in energy production (e.g. uraninite) are included in this group.

Mineral Reserve

The term is synonymously used for 'mineral reserve', 'probable mineral reserve' and 'proved mineral reserve'. 'Probable' and Proved' reflect increasing relative amounts of geological knowledge.

The standard CRIRSCO definition is: "A Mineral Reserve is the economically mineable part of a Measured and/or Indicated Mineral Resource.

It includes diluting materials and allowances for losses, which may occur when the material is mined or extracted and is defined by studies at Pre-Feasibility or Feasibility level as appropriate that include application of Modifying Factors.

Such studies demonstrate that, at the time of reporting, extraction could reasonably be justified".

N.B. Note that, within the Minventory portal, where indicators show presence of reserve data in a country by mineral, due to variations in State practice, this definition may not be the interpretation used by the State in question. Refer to the actual template, standard or code declared for that State. Such studies demonstrate that, at the time of reporting, extraction could reasonably be justified".

Mineral Resource

The term is synonymously used for 'mineral resource', 'inferred mineral resource', 'indicated mineral resource' and 'measured mineral resource. 'Inferred', 'Indicated', and 'Measured' reflect increasing relative amounts of geological knowledge.

The standard CRIRSCO definition is: "A Mineral Resource is a concentration or occurrence of solid material of economic interest in or on the Earth's crust in such form, grade or quality and quantity that there are reasonable prospects for eventual economic extraction. The location, quantity, grade or quality, continuity and other geological characteristics of a Mineral Resource are known, estimated or interpreted from specific geological evidence and knowledge, including sampling."

N.B. Note that, within the Minventory portal, where indicators show presence of resource data in a country by mineral, due to variations in State practice, this definition may not be the interpretation used by the State in question. Refer to the actual code, template or standard declared for that State.

Minerals Inventory

A part of the MIN4EU database containing both the Minerals Inventory and the electronic Minerals Yearbook. The minerals inventory is understood as information about primary mineral resources in Europe, more specifically data on mineral occurrences (either as point data or polygons) and mines (quarries/pits) collected by and automated 'harvesting' system at individual data providers in a harmonised and INSPIRE-compliant way. Besides from information on the geographical location and commodity/commodities, more information can be added, e.g. occurrence type, deposit or commodity group, importance, mining activity, ore measure, ore amount etc.

National Expert on mineral resources and reserves estimation

The role of a National Expert is to produce mineral resources and reserves estimates using a national Reporting Code, for the purpose of producing public authority reports and/or to assimilate information on mineral resources and reserves from data originators (for example, the minerals industry). These reports will comply with the national Reporting Code (if in use) or alternatively internal documented procedures which ensure consistency in the presentation of results. This task may involve, for example, statistical analysis and interpretation, data aggregation and addressing confidentiality issues. A National Expert is accountable for the prepared reports and must hold acceptable qualification titles as requested by the national authorities and where relevant the national Reporting Code. Therefore a National Expert is recognised by governments, international entities and, if they meet the requirements for a Competent Person, financial regulators.

Neighbouring countries

Countries neighbouring or closely associated with the EU28: Albania, Belarus, Bosnia, and Herzegovina, Greenland, Iceland, FYR Macedonia[1], Moldova, Montenegro, Norway, Serbia, Switzerland, Turkey and Ukraine.

non-energy minerals	All minerals except energy minerals. The non-energy minerals are divided into three sub-groups: construction minerals, industrial minerals and metalliferous minerals.
Open data	Data placed freely in the public domain from any source.
Primary raw materials	A primary raw material is a natural inorganic or organic substance, such as metallic ores, industrial minerals, construction materials or energy fuels, used for the first time. This may include previously unexploited raw materials from formerly abandoned mines. The scope of this work excludes agriculturally derived substances and energy reserves and resources. (Definition adapted from the INSPIRE Directive (2007/2/EC).)
Raw materials	As defined by the EU Raw Materials Strategy (COM (2011) 0025 final). Raw materials include metalliferous minerals, industrial minerals, and construction minerals but for the purposes of this project exclude wood and natural rubber.
RMI	An integrated EU strategy to address raw material availability, use and recovery that ties together various EU policies and promotes further cooperation between the Member States where appropriate. (See COM(2008)0699 of 4 Nov 2008)
RMKB	An EU-level initiative to aggregate data and information on raw materials from different sources in a harmonized and standardised way. (Action II.C (II.8) of the EIP-RM.)
RMSG	Mineral Expert Group set up by European Commission to assist the EC in relation to the implementation of existing Union legislation, programmes and policies and in the preparation of legislative proposals and policy initiatives and to coordinate with Member States, exchange of views; https://ec.europa.eu/transparency/expert-groups-register/screen/expert-groups/consult?do=groupDetail.groupDetail&groupID=1353
Statistical information on mineral resources and reserves	Numerical quantified data produced from the evaluation of mineral resources and reserves.

Acronyms

List of acronyms used in the course of GeoERA Raw Materials

1G-E	One Geology Europe
AGS	Albanian Geological Survey
B2G	Business to Government
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe (Federal Institute for Geosciences and Natural Resources, Germany)
BGS	British Geological Survey
BGS / Bulgaria	Bulgarian Geological Society
BLUE MINING	Breakthrough Solutions for the Sustainable Exploration and Extraction of Deep Sea Mineral Resources, FP 7 funded project, 2014 – 2018
BLUE Nodules	Breakthrough Solutions for the Sustainable Harvesting and Processing of Deep Sea Polymetallic Nodules, H2020 funded project, 2014 – 2018
BMLRT	Bundesministerium für Landwirtschaft, Regionen und Tourismus (Federal Ministry Republic of Austria - Agriculture, Regions and Tourism)
BRGM	Bureau de Recherches Géologiques et Minières (French Geological Survey)
CBA	Cell Based Association
CC-BY	One type of Creative Commons License
(C)EN	(Comité) Européen de Normalisation
CGS	Česká geologická služba (Czech Geological Survey)
CIP	Competitiveness and Innovation Framework Programme of the European Commission, 2007 – 2013
Comtrade	UN Commodities and trade database
CP	Competent person
CRIRSCO	Committee for Mineral Reserves International Reporting Code.
CRM	Critical Raw Materials (see e.g. European Commission, 2011 and subsequent papers)
CSA	Coordination and Support Action
CSD (GSD)	Τμήμα Γεωλογικής Επισκόπησης (Geological Survey Department, Cyprus)

DG	Directorate-General of the European Commission
EAC	The European Commission's Directorate for Education, Youth, Sport and Culture
EC	European Commission
ECE	Energy-Critical Elements
EESC	European Economic and Social Committee
EEZ	Exclusive Economic Zone
EFG	UNFC codes (E: Environmentally-socio-economic, F: Technical feasibility, G: Degree of confidence)
EGD	European Green Deal
EGDI	European Geological Data Infrastructure of the EGS hosted by GEUS
EGRM	The Expert Group on Resource Management (formerly known up until December 2018 as the Expert Group on Resource Classification
EGS	EuroGeoSurveys
EGT (GSE)	Eesti Geoloogiateenistus (Geological Survey of Estonia)
EI	Economic Importance
EIP-RM	European Innovation Partnership - Raw Materials.
EIT Raw Materials	European Institute of Innovation and Technology on Raw Materials
EMODnet	European Marine Observation and Data Network.
EMODnet-Geology	Thematic data portal under EMODnet
EMPIR	European Metrology Programme for Innovation and Research
e-MYB	European Electronic Minerals Yearbook, MINTELL4EU product
EPD	Environmental Product Declaration
ERA-MIN	European Institute of Innovation and Technology on Raw Materials
ERA-NET	European Research Area Net
ERMA	European Raw Materials Alliance
EU	European Union (Council, Parliament, Commission)
EURAMET	The European Association of National Metrology Institutes

EURare	Development of a sustainable exploitation scheme for Europe's Rare Earth ore deposits, FP7-NMP funded, 2013 – 2017
EURMBKB	European Raw Materials Knowledge Base
EuroGeoSource	EU Information and Policy Support System for Sustainable Supply of Europe with Energy and Mineral Resources, CIP-fund, 2010 – 2013
EuroLithos	European Ornamental Stone Resources, GeoERA scientific project lead by NGU
EUROROC	European and International Federation of Natural Stone Industries
Eurostat	The statistical office of the European Union
FAIR	Findability, Accessibility, Interoperability, and Reuse of digital assets in the context of scientific data management
FRAME	Forecasting and Assessing Europe's Strategic Raw Materials Needs, GeoERA scientific project lead by LNEG
GBA	Geologische Bundesanstalt (Geological Survey of Austria)
GEOINFORM	State Research and Development Enterprise State Information Geological Ukraine
GeoSeas	FP7 funded project 2009 – 2013
GeoZS	Geološki zavod Slovenije (Geological Survey of Slovenia)
GEUS	De Nationale Geologiske Undersøgelser for Danmark og Grønland (Geological Survey of Denmark and Greenland)
GIP-P	The GeoERA Information Platform Project
GIS	Geographical Information System
GROW	The European Commission's Directorate for the Internal Market, Industry, Entrepreneurship & SMEs
GSB	Geological Survey of Belgium
GSI	Geological Survey of Ireland
GSM	Geological Survey of Montenegro
GSO	Geological Survey Organisations
Gt	Gigatonne (metric unit of mass equal to 1012 kg)
GTK	Geologian tutkimuskeskus (Geological Survey of Finland)
H.S.G.M.E.	Hellenic Survey of Geology and Mineral Exploration (Geological Survey of Greece), formerly known as IGME-GR

HGI-CGS	Hrvatski geološki institut (Croatian Geological Survey)
iAtlantic	Integrated Assessment of Atlantic Marine Ecosystems in Space and Time, H2020 project
IGEO (UCM-CSIC)	Geosciences Institute, University of Madrid
IGME-CSIC	Instituto Geológico y Minero de España (Geological Survey of Spain), formerly known as IGME-SP
IGR (GIR)	Institutul Geologic al Romaniei (Geological Survey of Romania)
IKMS	Integrated Knowledge Management System developed by EUrare hosted by BRGM
InGeoCLOUDS	Inspired GEOdata CLOUD Services, CIP funded project, 2012 – 2014
INSPIRE	Infrastructure for Spatial Information in the European Community
ISA	International Seabed Authority
ÍSOR	Íslenskar orkurannsóknir (Iceland GeoSurvey)
ISPRA	Istituto Superiore per la Protezione e la Ricerca Ambientale (Geological Survey of Italy)
IUGS	International Union of Geological Science
JORC	Joint Ore Reserves Committee
JRC	Joint Research Centre of the European Union
LCA	Life Cycle Analysis
LGRB	Landesamt für Geologie, Rohstoffe und Bergbau Baden-Württemberg (Geological Survey of Baden-Württemberg, Germany)
LGT	Lietuvos Geologijos Tranyba (Geological Survey of Lithuania)
LIBS	Laser Induced Breakdown Spectroscopy
LNEG	Laboratório Nacional de Energia e Geologia I.P. (Geological Survey of Portugal)
LVGMC	Latvijas Vides, Ģeoloģijas un Meteoroloģijas Centrs (Latvian Environment, Geology and Meteorology Centre)
MAP	Mineral Resource Assessment Platform, EIT RM funded project, 2018 – 2021
MARE	The European Commission's Directorate for the Maritime Affairs and Fisheries
MICA	Mineral Intelligence Capacity Analysis, H2020 funded project, 2015 – 2018

MIDAS	Managing Impacts of Deep-seA reSource exploitation, FP 7 funded project, 2013 – 2016
MIN4EU	The European Minerals Intelligence Database accessible through EGDI
MINDeSEA	Seabed Mineral Deposits in European Seas: Metallogeny and Geological Potential for Strategic and Critical Raw Materials, GeoERA scientific project lead by IGME
Minerals4EU also M4EU	Minerals Intelligence Network for Europe, FP7-NMP funded project, 2013 – 2015
MINTELL4EU	Mineral Intelligence for Europe, GeoERA scientific project lead by GEUS
MREG	The EGS Mineral Resources Expert Group
NGO	Non-Governmental Organisation
NGU	Norges Geologiske Undersøkelse (Geolgical Survey of Norway)
NRCan	Natural Resources Canada
OGC	Open Geospatial Consortium
ORAMA	Optimising data collection for Primary and Secondary raw materials, H2020 funded, 2017 – 2019
PDAC	Prospectors & Developers Association of Canada
PGI-NRI	Polish Geological Institute – National Research Institute
POLINARES	POLicy for Natural RESouces, FP7-SSH funded project, 2010 – 2012
PPP	Public Private Partnership
PROMINE	Nano-particle products from new mineral resources in Europe, FP7-NMP funded project, 2009 – 2013
ProSUM	Prospecting Secondary Raw Materials in the Urban mine and Mining wastes, H2020 funded project, 2015 – 2017
R & I	Research and Innovation
RBINS	Royal Belgian Institute of Natural Sciences
REE	Rare Earth Elements
RESEERVE	Mineral potential of the ESEE region, EIT RM funded project, 2018 – 2021
RMI	Raw Materials Initiative
RMIS	Raw Materials Information System - hosted by JRC Ispra, Italy

RMKB	Raw Materials Knowledge Base
RMSG	Raw Materials Supply Group - Mineral Expert Group set up by European Commission
RTD	The European Commission's Directorate for Research, Innovation and Science
SCAN-Deep	Systematic Characterisation and Archiving of megafauNa on a regional scale in a Deep-sea area threatened by mining, H2020 funded project, 2018 – 2020
SCRREEN	Solutions for Critical Raw Materials – a European Expert Network, H2020 funded project, 2016 - 2019 with follow-up by SCRREEN2 (2020 – 2023)
SDG	Sustainable Development Goals
SEDEX	Sedimentary Exhalative
SGL	Service Géologique du Luxembourg (Geological Survey of Luxemburg)
SGSS	Servizio Geologico, Sismico e dei Suoli della Regione Emilia-Romagna
SGU	Sveriges Geologiska Undersökning (Geological Survey of Sweden)
SGUDS (SGIDS)	Statny Geologicky Ustav Dionyza Stura (State Geological Institute of Dionýz Štúr, Slovakia)
SIP	Strategic Implementation Plan
SME	Small and Medium-Sized Enterprises
SMS	Seafloor Massive Sulphides
SQL	Structured Query Language
SR	Supply Risk
SZTFH	Szabályozott Tevékenységek Felügyeleti Hatósága (Mining and Geological Survey of Hungary), formerly known as MBFSZ
TEUF	Treaty on the Functioning of the European Union
TNO	Nederlands Instituut voor Toegepaste Geowetenschappen (Geological Survey of the Netherlands)
UKRI	United Kingdom Research and Innovation (British Geological Survey)
UN	United Nations
UNCLOS	United Nations Convention on the Law of the Sea
UNECE	United Nations Economic Commission for Europe

UNFC	United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources
UNRMS	United Nations Resource Management System
USGS	United States Geological Survey
VNIIOkeangeologia	Academician I. S. GRAMBERG All-Russia Scientific Research Institute for Geology and Mineral Resources of the Ocean
VSEGEI	A. P. Karpinsky All Russia Geological Research Institute
WFS	Web Feature Service
XRF	X-Ray Fluorescence

Annex

List of Tables

Table A 1: *List of peer-reviewed papers GeoERA Raw Materials scientific projects, in alphabetic order of first author and year.*

Author(s)	Year	Title	Journal	ISSN/ URL / DOI	Project
Alcorn T, Monteys X, Blasco I, Lobato A, González J	2021	Are the pan-European seas a promising source for critical metals supply? GeoERA-MINDeSEA Marine Data and Information Management Best Practices.	Bollettino di Geofisica Teorica ed Applicata, 62	https://imdis.seadatanet.org/content/download/151922/file/IMDIS2021_proceedings.pdf	MINDeSEA
Blokhin M, Zarubina N, Mikhailik P, Elovskiy E, Ivanova Y, González FJ, Somoza L	2020	Discriminating formation and accumulation processes of some strategic metals in Fe-Mn deposits of the Atlantic Ocean.	World Journal of Engineering	https://doi.org/10.1108/WJE-10-2020-0526	MINDeSEA
Carvalho J, Lisboa, JV	2022	Sustainable Exploitation of Ornamental Limestones in Maciço Calcário Estremenho, Portugal	NGU Bulletin	https://www.ngu.no/side/ngu-bulletin	EuroLithos
Decrée S, Savolainen M, Mercadier J, Debaille V, Höhn S, Frimmel H, Bael JM	2020	Geochemical and spectroscopic investigation of apatite in the Siilinjärvi carbonatite complex: Keys to understanding apatite forming processes and assessing potential for rare earth elements	Applied Geochemistry, 2020, 123	https://doi.org/10.1016/j.apgeochem.2020.104778	FRAME
Dehain Q, Tijsselin LT, Glas HJ, Törmäne T, Butche AR	2021	Geometallurgy of cobalt ores: A review	Minerals engineering 2021, 160	https://doi.org/10.1016/j.mineng.2020.106656	FRAME
Fernández Suárez J, Martínez-Martínez J, Álvarez Areces E, Baltuille Martín JM	2021	La roca ornamental europea y su vinculación al patrimonio arquitectónico: el proyecto Eurolithos	X GEOLOGICAL CONGRESS OF SPAIN (X CONGRESO GEOLÓGICO DE ESPAÑA)	https://sites.google.com/view/x-cge/inicio/programaci%C3%B3n	EuroLithos
Girta M, Wittenberg A, Grill ML, de Oliveira DPS, Giosu C, Ruello ML	2021	The Critical Raw Materials Issue between Scarcity, Supply Risk, and Unique Properties.	Materials 2021, 14, 1826	https://doi.org/10.3390/ma14081826	FRAME
González FJ, Medialdea T, Schiellerup H, Zananiri I, Ferreira P, Somoza L, Monteys X, the MINDeSEA Team	2020	Are the pan-European seas a promising source for critical metals supply? The project GeoERA-MINDeSEA.	European Geologist Journal 49, 37-41	https://eurogeologists.eu/gonzales-are-the-pan-european-seas-a-promising-source-for-critical-metals-supply-the-project-geoera-mindesea/	MINDeSEA

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Author(s)	Year	Title	Journal	ISSN/ URL / DOI	Project
González FJ, Rincón-Tomás B, Somoza L, Santofimia E, Medialdea T, Madureira P, LópezPamo E, Hein JR, Marino E, de Ignacio C, Reyes J, Hoppert M, Reitner J	2020	Low-temperature shallow-water hydrothermal vent mineralization following the recent submarine eruption of Tagoro volcano (El Hierro Canary Islands).	Marine Geology, 430	https://doi.org/10.1016/j.margeo.2020.106333	MINDeSEA
González FJ, Somoza L, Medialdea T, Marino E, Blasco I, Lobato A, GeoERA-MINDeSEA Project	2021	GeoERA-MINDeSEA Project: Establishing the metallogenic context for seabed mineral deposits in the pan-European seas.	Geo-Temas, 18, 753	ISSN: 1576-5172.	MINDeSEA
Heldal T	2022	Natural Stone in Norway: Overview and Perspectives	NGU Bulletin	https://www.ngu.no/side/ngu-bulletin	EuroLithos
Heldal T, Aasly KA, Granseth A	2022	Non-Economic Value Assessment of Complex Stone Quarry Landscapes: the Example of the Iddefjord Granite	NGU Bulletin	https://www.ngu.no/side/ngu-bulletin	EuroLithos
Junge M, Kolb AC, Wittenberg A, Sievers H, Gega D, Onuzi K	2021	Mineralogical characterization of podiform chromitite deposits in the Eastern Mirdita Ophiolite, Albania	ZDGG, 172 (1), 1-17	DOI: 10.1127/zdgg/2021/0266	FRAME
Kfouri LO, Millo C, de Lima AE, Silveira CS, Sant'Anna LG, Marino E, González FJ, Murton BJ	2021	Growth of ferromanganese crusts on bioturbated soft substrate Tropic Seamount northeast Atlantic Ocean.	Deep Sea Research Part I: Oceanographic Research Papers 175, 103586	https://doi.org/10.1016/j.dsr.2021.103586	MINDeSEA
Laskaridis KN, Arapakou AE, Patronis M	2022	Effect of freeze - thaw cycles on the flexural strength of natural stones	NGU Bulletin	https://www.ngu.no/side/ngu-bulletin	EuroLithos
Małek R, Mikulski SZ	2021	A rare indium-bearing mineral (Zn-In-Cu-Fe sulphide) from the Stara Kamienica Schist Belt (Sudetes, SW Poland).	Geological Quarterly 2021, 65(1), 7: 2	https://gq.pgi.gov.pl/issue/view/23435	FRAME
Marino E, González FJ, Kuhn T, Madureira P, Wegorzewski AV, Mirao J, Medialdea T, Oeser M, Miguel C, Reyes J, Somoza L, Lunar R	2019	Hydrogenetic Diagenetic and Hydrothermal Processes Forming Ferromanganese Crusts in the Canary Islands Seamounts and their Influence in the Metal Recovery Rate with Hydrometallurgical Methods.	Minerals 9 439	https://doi.org/10.3390/min9070439	MINDeSEA

continuation table A 1

Author(s)	Year	Title	Journal	ISSN/ URL / DOI	Project
Marino E, González FJ, Lunar R, Reyes J, Medialdea T, Castillo-Carrión M, Bellido E, Somoza L	2018	High-Resolution Analysis of Critical Minerals and Elements in Fe–Mn Crusts from the Canary Island Seamount Province (Atlantic Ocean).	Minerals, 8, 285	https://doi.org/10.3390/min8070285	MINDeSEA
Mikulski SZ, Małek R	2019	Indium and other critical elements enrichment in cassiterite-sulphide Mineralization from the stratiform tin deposits in the West Sudetes (SW Poland). Life with Ore Deposits on Earth	15th SGA Biennial Meeting, 27-30 August 2019, Glasgow, Scotland, Volume 4:1818-1822	https://e-sga.org/nc/publications/sga-biennialmeetings-abstract-volumes/2019-glasgow/	FRAME
Mikulski SZ, Oszczepalski S, Sadłowska K, Chmielewski A, Małek R	2020	Trace Element Distributions in the Zn-Pb (Mississippi Valley-Type) and Cu-Ag (Kupferschiefer) Sediment-Hosted Deposits in Poland	Minerals 2020, 10(1), 75	https://doi.org/10.3390/min10010075	FRAME
Mikulski SZ, Sadłowska K	2019	The critical elements (V, Co, Ga, Sc, REE) enrichment of Fe-Ti-V oxide deposits related to Mesoproterozoic AMCG complex in Poland. Life with Ore Deposits on Earth	15th SGA Biennial Meeting, 27-30 August 2019, Glasgow, Scotland, Volume 4:1814-1817	https://e-sga.org/nc/publications/sga-biennialmeetings-abstract-volumes/2019-glasgow/	FRAME
Miletić S, Novak M	2021	SLOVENIAN NATURAL STONE in the EUROPEAN STONE INVENTORY	Mineral Resource Bulletin	https://www.geo-zs.si/index.php/en/products/publications2/periodicals/mineral-resources	EuroLithos
Navarro R, Martínez-Martínez J, Fernández Suárez J, Álvarez Areces E, Baltuille Martín JM	2021	Comparative analysis of the current uneven situation of historical quarries associated with the UNESCO world heritage sites in Spain	Resources Policy 75, 102471	https://doi.org/10.1016/j.resourpol.2021.102471	EuroLithos
Rincón-Tomás B, Duda JP, Somoza L, González FJ, Schneider D, Medialdea T, Santofimia E, López-Pamo E, Madureira P, Hoppert M, Reitner J	2019	Cold-water corals and hydrocarbon-rich seepage in Pompeia Province (Gulf of Cádiz)–living on the edge	Biogeosciences 16,1607–1627	http://doi.org/10.5194/bg-16-1607-2019	MINDeSEA
Rincón-Tomás B, González FJ, Somoza L, Sauter K, Madureira P, Medialdea T, Carlsson J, Reitner J, Hoppert M	2020	Siboglinidae Tubes as an Additional Niche for Microbial Communities in the Gulf of Cádiz—A Microscopical Appraisal.	Microorganisms 8, (3) 367	https://doi.org/10.3390/microorganisms8030367	MINDeSEA

continuation table A 1

Author(s)	Year	Title	Journal	ISSN/ URL / DOI	Project
Somoza L, González FJ (Special Issue Editors)	2020	Marine Geology and Minerals.	Minerals, 10	https://www.mdpi.com/journal/minerals/special_issues/marine_geology_minerals	MINDeSEA
Somoza L, Medialdea T, González FJ, Calado A, Afonso A, Albuquerque M, Asensio-Ramos M, Bettencourt R, Blasco I, Candón JA, Carreiro-Silva M, Cid C, De Ignacio C, López-Pamo E, Machancoses S, Ramos B Ribeiro LP, Rincón-Tomás B, Santofimia E, Souto M, Tojeira I, Viegas C, Madureira P	2020	Multidisciplinary Scientific Cruise to the Northern Mid-Atlantic Ridge and Azores Archipelago.	Frontiers in Marine Sciences, 7: 568035	https://doi.org/10.3389/fmars.2020.568035	MINDeSEA
Somoza L, Medialdea T, González FJ, León R, Palomino D, Rengel J, Fernández-Salas LM, Vázquez JT	2019	Morphostructure of the Galicia continental margin and adjacent deep ocean floor: From hyperextended rifted to convergent margin styles.	Marine Geology 407, 299-315	https://doi.org/10.1016/j.margeo.2018.11.011	MINDeSEA
Somoza L, Medialdea T, González FJ, Machancoses S, Candón JA, Cid C, Calado A, Afonso A, Pinto L, Blasco I, Albuquerque M, Asensio-Ramos M, Bettencourt R, De Ignacio C, LópezPamo E, Ramos B, Rincón-Tomás B, Santofimia E, Souto M, Tojeira I, Viegas C, Madureira P	2021	High-resolution multibeam bathymetry of the northern Mid-Atlantic Ridge at 45–46° N: the Moytirra hydrothermal field.	Journal of Maps 17	https://doi.org/10.1080/17445647.2021.1898485	MINDeSEA
Somoza L, Rueda JL, Sánchez-Guillamón O, Medialdea T, Rincón-Tomás B, González FJ, Vázquez JT	2021	The Interactive Role of Hydrocarbon Seeps Hydrothermal Vents and Intermediate Antarctic/Mediterranean Water Masses on the Distribution of Some Vulnerable Deep-Sea Habitats in Mid Latitude NE Atlantic Ocean.	Oceans 2 (2) 351-385	https://doi.org/10.3390/oceans2020021	MINDeSEA
Teran K	2019	Critcal Raw Materials (CRM) in Slovenia.	Bulletin of Mineral Resources in Slovenia, GeoZS, 2019	ISSN 1855-4725	FRAME

continuation table A 1

Author(s)	Year	Title	Journal	ISSN/ URL / DOI	Project
Terrinha P, Medialdea T, Batista L, Somoza L, Magalhães V, González FJ, Noiva J, Lobato A, Rosa M, Marino E, Brito P, Neres M, Ribeiro C	*2020*	*Integrated thematic geological mapping of the Atlantic Margin of Iberia.*	*Geological Society London, Special Publications 505*	https://doi.org/10.1144/SP505-2019-90	*MINDeSEA*
Wittenberg A, Oliveira D, Jørgensen L, González J, Heldal T	*2021*	*GeoERA Raw Materials to support Europe's resilience on raw materials.*	*Society of Geology Applied to Mineral Deposits (SGA) News, 48*	https://e-sga.org/fileadmin/sga/newsletter/news48/SGANews48_low.pdf	*GeoERA Raw Materials*
Zalba I, González FJ, Fernández-Puga MC, Nyberg J	*2021*	*Ferromanganese concretions in the Baltic Sea: characterization and forming processes.*	*Geo-Temas, 18, 775-778*	*ISSN: 1576-5172*	*MINDeSEA*

Table A 2: *List of abstracts / conference / newspaper / workshops with contributions by GeoERA Raw Materials scientific projects that are of scientific/technical relevance. Listed in alphabethic order of first auther.*

Author(s)	Year	Title	Conference / Workshop / Newspaper	ISSN/ URL / DOI	Project
Aasly K, Eilu P, Schjøth F, Jørgensen LF	2021	Testing UNFC as a harmonized supporting tool for resource management in Europe	EGU2021, 19-30 April 2021, online	https://doi.org/10.5194/egusphere-egu21-15566	MINTELL4EU
Aasly K, Simoni M, Eilu P, Jørgensen LF	2021	Towards a harmonised inventory for European mineral resources	EGU2021, 19-30 April 2021, online	https://www.conftool.pro/geokarlsruhe2021/index.php?page=browseSessions-&form_session=189&-presentations=hide	MINTELL4EU
Aasly KA	2021	UNFC work in MINTELL4EU with Norwegian case study	UNECE Resource Management Week 2021 – 12th Session of the Expert Group on Resource Management. Enabling sustainability principles in resource management, 26 – 30 April 2021	https://unece.org/sed/documents/2021/04/presentations/nfc-work-mintell4eu-norwegian-case-study-kari-aslaksen-aasly	MINTELL4EU
Bertrand G, Sadeghi M, de Oliveira D, Tourlière B, Arvanitidis N, Gautneb H, Gloaguen E, Törmänen T, Reginiussen H, Decrée S, Pereira A, Quental L, De Oliveira D	2021	Mineral prospectivity mapping for critical raw materials at the European Scale with the CBA method. Geological Survey of Finland	Open File research Report 57/2021 – Mineral Prospectivity and Exploration Targeting – MinProXT 2021 Webinar, pg. 79 – 82.	https://tupa.gtk.fi/raportti/arkisto/57_2021.pdf	FRAME
Bertrand, G	2020	Mineral Prospectivity Mapping for energy critical elements in Europe: the Cell Based Association approach - FRAME project	Mineral Exploration Symposium, 17 – 18. Sep. 2020, online	https://eage.eventsair.com/mineral-exploration-symposium/	FRAME
Bide T	2021	Perspective of use of UNFC in the UK and its applications by National Geological Surveys	UNECE Resource Management Week 2021 - 12th Session of the Expert Group on Resource Management. Enabling sustainability principles in resource management, 26 – 30 April 2021	https://unece.org/sed/documents/2021/04/presentations/perspective-use-unfc-uk-and-its-applications-national	MINTELL4EU

continuation table A 2

Author(s)	Year	Title	Conference / Workshop / Newspaper	ISSN/ URL / DOI	Project
Blasco I, Blanco L	2018	MINDeSEA: Un Proyecto Europeo para cartografiar los depósitos minerales submarinos.	ESRI Spain Conference. Annual ESRI Meeting 2018	https://www.slideshare.net/esriespana/mindesea-un-proyecto-europeo-para-cartografiar-los-depsitos-minerales-submarinos	MINDeSEA
Blasco I, the MINDeSEA Team	2019	Oceania. Expedicion Mar Azúl.	COP 25, Madrid, Spain	https://pressroom.media-toolstv.com/expedicion-oceania--en-el-cop25/	MINDeSEA
Cetean V	2021	Limestone historical quarry from Magura Calanului	DACICA Conferences, 7	https://youtu.be/gu2zXa6J-7Do	EuroLithos
Cetean V	2021	Magura Calanului - Reading in stone, after two millennia of silence, the history of the limestone quarry of the Dacians it begins to be written step by step ...	Webinar about Magura Calanului Dacian historical quarry in projects: RoQ-Stone - Romanian stone for construction – quality, cultural heritage value, scientific designation EUROLITHOS – European Ornamental stone resources	https://magura-calanului.ro/wp-content/uploads/2021/04/IGR-Invitatie-Prezentare_Magura-Calanului-EN.pdf	EuroLithos
Cetean V, Fărnoagă R, Geanta M, Ciprian Rus	2020	Pietrarii lui Burebista, cercetați de geologi	Reportage - Burebista's stonemasons, researched by geologists	https://www.formula-as.ro/2020/07/27/pietrarii-lui-burebista-cercetati-de-geologi/	EuroLithos
Cetean V, Fărnoagă R, Rusu E, Ulmeanu A, Scutelnicu I, Filipciuc C, Tătaru A	2021	Research to determine the limestone exploitation geometry in the dacian historical quarry from Magura Calanul	II International workshop on Heritage stones, 5 – 7 October 2021, Turin, Italy	https://www.diati.polito.it/en/outreach/dissemination_and_public_engagement/workshop_on_heritage_stones	EuroLithos
Cetean V, Petan A	2019	Romanian heritage stone with international historical significance - the ooidal limestone from M Magura Čalanului pre-Roman quarr	EGU 2019, 21, EGU2019-4351, Vienna	https://meetingorganizer.copernicus.org/EGU2019/EGU2019-4351.pdf	EuroLithos
De Oliveira D, the FRAME Team	2019	Sustainability of SCRM on Europe	Raw Materials Week 2019, 18 – 22 Nov 2019, Brussels, Belgium	Poster	FRAME
de Oliveira DPS, Ferreira MJ, Sadeghi M, Arvanitidis N, Bertrand G, Decrée S, Gautneb H, Gloaguen E, Törmänen T, Reginiussen H, Sievers H, Quental L, Wittenberg A	2020	FRAME's (Forecasting and Assessing Europe's Strategic Raw Materials Needs) innovative research in mineral raw materials on the eve of the EU's "Green Deal"	GeoUtrecht2020, 21 – 26. Aug. 2020, online	DOI: 10.48380/dvpe-hm22	FRAME

continuation table A 2

Author(s)	Year	Title	Conference / Workshop / Newspaper	ISSN/ URL / DOI	Project
de Oliveira DPS, Ferreira MJ, Sadeghi M, Arvanitidis N, Decrée S, Gautneb H, Gloaguen E, Törmänen T, Reginuissesn H, Sievers H, Quental L, Wittenberg A,	2020	FRAME's (Forecasting and Assessing Europe's Strategic Raw Materials Needs) contribution to the "European Green Deal"	EGU2020, 4 – 8 May 2020, online	https://doi.org/10.5194/egusphere-egu2020-5950	FRAME
de Oliveira DPS, Gonzalez FJ, (Wittenberg A)	2020	FRAME and MINDeSEA: Where land meets sea in the research, prediction and prospectivity of metallic mineral critical raw materials	GeoUtrecht2020, 21 – 6. Aug. 2020, online	DOI: 10.48380/AHDB-BQ72	FRAME
de Oliveira DPS, González Sanz FJ	2021	Mapping and studying the European critical elements in submarine and on-land deposits for the sustainable development	Critical Mineral Forum, 19 Feb 2021, online	https://www.americangeosciences.org/webinars/critical-minerals-forum-2021	FRAME - MINDeSEA
de Oliveira, D	2021	Minerales Criticos y Estratégicos en Iberoamerica	Ciclo de Seminarios ASGMI, 9 – 10 Nov 2021, online	https://asgmi.org/webinar-minerales-criticos-presentaciones/	FRAME
de Oliveira, D	2021	EuroGeoSurveys (EGS) Mineral Resources Expert Group research on CRM	GREENPEG Project Newsletter, Issue 2, June 2021.	https://geoera.eu/wp-content/uploads/2021/06/GREENPEG-NEWSLETTER-June-2021-final-FL.pdf	FRAME
de Oliveira, DP	2021	Towards a green future – Where is the critical raw material resource potential in Europe?	GeoKarlsruhe 2021, 19 – 23 Sep. 2021, online	https://www.conftool.pro/geokarlsruhe2021/index.php?page=browseSessions&form_session=31&presentations=hide	FRAME
de Oliveira, DPS	2021	Mitigating the European dependency of mineral raw materials: The role of the Mineral Resources Expert Group and GeoERA Raw Materials	International Conference on Raw Materials and Circular Economy – RawMat2021, 05 – 09 Sept 2021, Athens, Greece	https://www.rawmat2021.gr/congress/wp-content/uploads/2021/10/Book-of-Abstracts-RawMat2021.pdf	FRAME
Deady E, Kumelj Š, Jørgensen LF	2021	MINTELL4EU; the European Minerals Yearbook	EGU2021, 19 – 30 April 2021, online	https://www.conftool.pro/geokarlsruhe2021/index.php?page=browseSessions&form_session=-31&presentations=hide	MINTELL4EU
Decrée, S	2020	Assessment of Critical Raw Materials content in Phosphate mineralizations: an objective of the FRAME project	Mineral Exploration Symposium, 17 – 18. Sep. 2020, online	https://eage.eventsair.com/mineral-exploration-symposium/	FRAME

continuation table A 2

Author(s)	Year	Title	Conference / Workshop / Newspaper	ISSN/ URL / DOI	Project
Eilu P, Hokka J		The Jouhineva Co-Cu-Au Deposit, Finland: The 1984 Mineral Ressource Mapped into UNFC	Raw Materials Week 2020: UNFC Europe: Ensuring sustainable raw material management to support the European Green Deal. Virtual Workshop Nov. 19, 2020	https://unece.org/fileadmin/DAM/energy/se/pdfs/UNFC/EU_Raw_Materials_Week_2020/S2P5_Jouhineva_CoAuCu_resources_UNFCcoded.pdf	MINTELL4EU
Eilu P, Hokka J	2021	UNFC case study and guidance from Finland	UNECE Resource Management Week 2021 – 12th Session of the Expert Group on Resource Management. Enabling sustainability principles in resource management, 26 – 30 April 2021	https://unece.org/sed/documents/2021/04/presentations/unfc-case-study-and-guidance-finland-pasi-eilu-and-janne-hokka	MINTELL4EU
Eliasson T	2019	Natursten i kulturhistoriskt viktiga byggnader i Göteborg	Heritage Science Forum 2019, Presentation of historical use of stones in buildings	http://www.diva-portal.org/smash/get/diva2:1430556/FULLTEXT01.pdf	EuroLithos
Eliasson T	2021	Naturreportaget: Så bakas en gnejs	Heritage stone history	https://sverigesradio.se/artikel/naturreportaget-sa-bakas-en-gnejs	EuroLithos
Fernández Suárez J, Martínez-Martínez J, Álvarez Areces E, Baltuille Martín JM	2021	European ornamental stone and its link to architectural heritage: the Eurolithos project	Geo-Temas, 18, 899-902 (spanish with english abstract)	https://sge.usal.es/archivos/GEO_TEMAS/Geo_temas18.pdf	EuroLithos
Ferreira P, Gonzalez FJ, Kuhn T, Nyberg J, Marino E, Rühlemann C, Magalhães V, the MINDeSEA Team	2021	Occurrences of polymetallic nodules in European seas - preliminary results of the MINDeSEA project.	Goldschmidt Conference 2019, 18 – 23 August 2019, Barcelona, Spain	https://2021.goldschmidt.info/goldschmidt/2021/meetingapp.cgi/Paper/5797	MINDeSEA
Ferreira P, Gonzalez FJ, Kuhn T, Nyberg J, Marino E, Rühlemann C, Moniz C, Magalhães V, the MINDeSEA Team	2021	MINDeSEA database for polymetallic nodules – occurrences and some geochemical features	XV Congresso de Geoquimica dos Paises da Lingua Portuguesa, 22 – 24 Aug 2021, online	http://xvcgplp-2021.com.br/	MINDeSEA
Gautneb H, Gloaguen E, Törmänen T	2020	Lithium, Cobalt and Graphite occurrences in Europe, Results from GeoEra FRAME project wp 5	EGU2020, 4 – 8 May 2020, online	https://doi.org/10.5194/egusphere-egu2020-7025	FRAME
Gautneb H, the FRAME Team	2019	SCRM occurrences Preliminary Map on Co, Li, and Graphite	Raw Materials Week 2019, 18 – 22 Nov 2019, Brussels, Belgium	Poster	FRAME

continuation table A 2

Author(s)	Year	Title	Conference / Workshop / Newspaper	ISSN/ URL / DOI	Project
González FJ, Somoza L, Marino E, Reyes J, Castillo-Carrión M, Medialdea T, Blasco I	2018	Cobalt, tellurium and other critical elements distribution in ferromanganese crusts from the Canary Island Seamount Province (NE Central Atlantic).	Joint International Conference, Minerals of the Ocean- 9, 05 – 07 June 2018, St. Petersburg, Russia	http://vniio.ru/upload/iblock/a2a/a2aa98a29108e23d043626edd8f291ee.pdf	MINDeSEA
González FJ, Marino E, Blasco I, Ferreira P, Magalhaes V, Kuhn T, the MINDeSEA team	2020	GeoERA-MINDeSEA project: evaluating ferromanganese crusts and their associated critical metals in European seas	36th International Geological Congress	https://www.36igc.org/	MINDeSEA
González FJ, Medialdea T, Schiellerup H, Zananiri I, Ferreira P, Somoza L, Monteys X, Alcorn T, Marino E, Lobato A, Kuhn T, Nyberg J, Magalhaes V, Lunar R, Maliuk B, Hein JR, Cherkashov G, and the MINDeSEA Team	2021	GeoERA-MINDeSEA project database and cartography of European seabed mineral deposits	Deep Sea Minerals Conference, 19 – 21 Oct. 2021, Bergen, Norway	https://events.geonova.no/event/deep-sea-minerals-2021/	MINDeSEA
González FJ, Medialdea T, Schiellerup H, Zananiri I, Ferreira P, Somoza L, Monteys X, Alcorn T, Blasco I, Lobato A, Kuhn T, Nyberg J, Melnyk I, Magalhaes V, Lunar R, Martínez-Frías J, Marino E, Hein JR, Cherkashov G, the MINDeSEA Team	2020	An integrative metallogenetic study of seabed mineral deposits in the pan-European seas: The project GeoERA- MINDeSEA.	Underwater Minerals Conference - 49th UMC 2020, 27 Sept – 2 Oct 2020, St. Petersburg, USA	https://www.underwaterminerals.org/_files/ugd/cacc41_da306712968f43e8b6196eb055815347.pdf	MINDeSEA
González FJ, Somoza L, Medialdea T, Kuhn T, Zananiri I, Judge M, Stanley G, Schiellerup H, Ferreira P, Nyberg J, Malyuk B, Terrinha P, Magalhaes V, Lunar R, Martínez-Frías J, Hein JR, Cherkashov G, and the MINDeSEA Scientific Party	2018	Seabed Mineral Deposits in European Seas: Metallogeny and Geological Potential for Strategic and Critical Raw Materials (MINDeSEA Project)	Underwater Minerals Conference - 47th UMC, 10 – 14 Sept 2018, Bergen, Norway	https://www.underwaterminerals.org/_files/ugd/cacc41_4f55964e658b45809a036e4d3761ede0.pdf	MINDeSEA
González FJ, Somoza L, Medialdea T, Marino E, Blasco I, Lobato A	2021	GeoERA-MINDeSEA Project: Establishing the metallogenic context for seabed mineral deposits in the pan-European seas.	10th Geological Congress of Spain, 5 – 7 July 2021, Vitoria-Gasteiz, Spain	https://sites.google.com/view/x-cge/inicio/programaci%C3%B3n	MINDeSEA

continuation table A 2

Author(s)	Year	Title	Conference / Workshop / Newspaper	ISSN/ URL / DOI	Project
González FJ, Somoza L, Medialdea T, Zananiri I, Schiellerup H, the MINDeSEA Scientific Party	2018	Earth observation systems and marine minerals: Copernicus and MINDeSEA links.	Raw Materials Week 2018, 12 – 16 November 2018, Brussels, Belgium	Poster	MINDeSEA
González FJ, Somoza L, Terrinha P, Medialdea T, Magalhaes V, Madureira P, Ferreira P, Marino E	2018	The Atlantic Iberian and Macaronesian margins: A promising context in critical raw materials exploration.	Geological Society of London, Marine Minerals: A New Resource for the 21st Century, 31 Oct – 01 Nov 2018, London, United Kingdom	Marine Minerals: A New Resource for the 21st Century | SUT | Society for Underwater Technology	MINDeSEA
González FJ, the MINDeSEA Team	2019	SCRM occurrences from seafloor mineral deposits.	Raw Materials Week 2019, 18 – 22 Nov 2019, Brussels, Belgium	Poster	MINDeSEA
Gonzalez J, Medialdea T, Schiellerup H, Zananiri, I Ferreira P, Somoza L, Montey, X, Alcorn T, Marino E, Lobato A, Kuhn T, Nyberg J, Magalhaes, V Lunar R, Malyuk B, Hein J, Cherkashov G	2021	The family of battery metals found in European seabed mineral deposits: The MINDeSEA perspective	GeoKarlsruhe 2021, 19 – 23 Sep. 2021, online	https://www.conftool.pro/geokarlsruhe2021/index.php?page=browseSessions&form_session=-31&presentations=hide	MINDeSEA
González J, Medialdea T, Schiellerup H, Zananiri I, Ferreira P, Somoza L, MINDeSEA Team	2020	Critical minerals in the European seas: The project GeoERA-MINDeSEA.	EGU2020, 4 – 8 May 2020, online	https://doi.org/10.5194/egusphere-egu2020-13271	MINDeSEA
González FJ, MINDeSEA Scientic Party	2019	GeoERA-MINDeSEA project: mapping and studying critical elements in the pan-European seabed mineral deposits.	Goldschmidt Conference 2019, 18 – 23 August 2019, Barcelona, Spain	https://goldschmidtabstracts.info/2019/1174.pdf	MINDeSEA
González FJ, the MINDeSEA Team	2019	GeoERA-MINDeSEA project	Prospectors & Developers Association of Canada (PDAC 2019)	https://www.pdac.ca/	MINDeSEA
González, FJ, the MINDeSEA Team	2020	GeoERA-MINDeSEA project.	Prospectors & Developers Association of Canada (PDAC 2020)	https://www.pdac.ca/	MINDeSEA
González, FJ, the MINDeSEA Team	2021	GeoERA-MINDeSEA project	Prospectors & Developers Association of Canada (PDAC 2021)	https://www.pdac.ca/	MINDeSEA

continuation table A 2

Author(s)	Year	Title	Conference / Workshop / Newspaper	ISSN/ URL / DOI	Project
Heldal T	2021	Non-Economic Value Assessment of Complex Stone Quarry Landscapes: the Example of the Iddefjord Granite	II International workshop on Heritage stones, 5 – 7 October 2021, Turin, Italy	https://www.diati.polito.it/en/outreach/dissemination_and_public_engagement/workshop_on_heritage_stones	EuroLithos
Heldal T, Aslaksen Aasly K	2021	Value assessment of ornamental stone resources	EGU2021, 19 – 30 April 2021, online	https://doi.org/10.5194/egusphere-egu21-14730	EuroLithos
Heldal T, Carvalho J	2020	Natural stone resources and sustainability	GeoUtrecht2020, 21 – 26. Aug. 2020, online	DOI: 10.48380/ dggv-ny33-gm92	EuroLithos
Heldal T, Carvalho J, Dedić Ž, Laskardis K	2020	Atlas of European ornamental stone resources	EGU2020, 4 – 8 May 2020, online	https://doi.org/10.5194/egusphere-egu2020-20781	EuroLithos
Heldal T, the EuroLithos Team	2019	EuroLithos – European Ornamental Stone Resources	Raw Materials Week 2019, 18 – 22 Nov 2019, Brussels, Belgium	Poster	EuroLithos
Hokka J, Eilu P	2021	UNFC resources reporting code and national mineral resources accounting	EGU2021, 19 – 30 April 2021, online	https://www.conftool.pro/geokarlsruhe2021/index.php?-page=browseSessions&-form_session=189&-presentations=hide	MINTELL4EU
Horváth Z		UNFC in Europe: A Review of Good Practices from Geological Surveys	Raw Materials Week 2020: UNFC Europe: Ensuring sustainable raw material management to support the European Green Deal. Virtual Workshop Nov. 19, 2020	https://unece.org/fileadmin/DAM/energy/se/pdfs/UNFC/EU_Raw_Materials_Week_2020/S2P2_UNFC_Europe_Session_2_HZ.pdf	MINTELL4EU
Horváth Z	2021	Hungarian progress with UNFC	UNECE Resource Management Week 202 – 12th Session of the Expert Group on Resource Management. Enabling sustainability principles in resource management, 26 – 30 April 2021	https://unece.org/sed/documents/2021/04/presentations/hungarian-progress-unfc-zoltan-horvath-and-gabor-kovacs-mbfsz	MINTELL4EU

continuation table A 2

Author(s)	Year	Title	Conference / Workshop / Newspaper	ISSN/ URL / DOI	Project
Horváth Z, Oliveira D	2021	EGS activities and future plans	UNECE Resource Management Week 2021 – 12th Session of the Expert Group on Resource Management. Enabling sustainability principles in resource management, 26 – 30 April 2021	https://unece.org/sed/documents/2021/04/presentations/egs-activities-and-future-plans-zoltan-horvath-egs-and-mining	MINTELL4EU
Horváth Z, Oliveira D, Aasly KA, Simoni M, Jørgensen LF, Whitehead D, Wittenberg A, Kral U, Griffiths C, Tulsidas H, Solar S	2020	UN Framework Classification - a tool for Sustainable Resource Management	GeoUtrecht2020, 21 – 26 Aug. 2020, online	DOI: 10.48380/dggv-dakj-bn91	FRAME, MINTELL4EU
Ingvald E		UNFC Case Studies and Industry Perspectives from Northern Europe	Raw Materials Week 2020: UNFC Europe: Ensuring sustainable raw material management to support the European Green Deal. Virtual Workshop Nov. 19, 2020	https://unece.org/fileadmin/DAM/energy/se/pdfs/UNFC/EU_Raw_Materials_Week_2020/S2P6_PPT_Template_UNECE__Webinar_MAWG_ei.pdf	MINTELL4EU
Ingvald E	2021	UNFC Case study - REE, exploration prospects and secondary resources in Sweden	UNECE Resource Management Week 2021 – 12th Session of the Expert Group on Resource Management. Enabling sustainability principles in resource management, 26 – 30 April 2021	https://unece.org/sed/documents/2021/04/presentations/unfc-case-study-ree-exploration-prospects-and-secondary	MINTELL4EU
Jørgensen LF, Deady E, Kumelj Š, Aasly KA, Urvois M, Tulstrup J, Pedersen M	2021	Harmonised data on European raw materials, the creation and content of the MIN4EU database	EGU2021, 19 – 30 April 2021, online	https://www.conftool.pro/geokarlsruhe2021/index.php?-page=browseSessions&-form_session=31&-presentations=hide	MINTELL4EU
Jørgensen LF, Kumelj Š, Brown T	2021	Collecting, harmonizing and sharing data on European Raw Materials	EGU2021, 19 – 30 April 2021, online	https://doi.org/10.5194/egusphere-egu21-14690	MINTELL4EU
Junge M, Kolb AC, Wittenberg A, Sievers H, Gega D, Onuzi K	2020	Mineralogical characterization of podiform chromitite deposit in the Eastern Mirdita Ophiolite, Albania	GeoUtrecht2020, 21 – 26. Aug. 2020, online	DOI: 10.48380/dggv-4dkw-0549	FRAME

continuation table A 2

Author(s)	Year	Title	Conference / Workshop / Newspaper	ISSN/ URL / DOI	Project
Knoll T, Huet B, Schuster R, Mali H	2020	An anatectic model for albite-spodumene pegmatites from the Austroalpine Unit (Eastern Alps)	GeoUtrecht2020, 21 – 26. Aug. 2020, online	DOI: 10.48380/dggv-j4sz-6639	FRAME, MINTELL4EU
Kumelj S, Jørgensen LF, Schjøth F, Vihtelič A, Bahar B, Hribernik K	2021	Collecting, sharing, and visualising harmonised data on European raw materials occurrences and mines – success or failure?	GeoKarlsruhe 2021, 19 – 23 Sep. 2021, online	https://www.conftool.pro/geokarlsruhe2021/index.php?page=browseSessions&form_session=189&presentations=hide	MINTELL4EU
Kumelj S, Šinigoj J, Rokavec D, Vihtelič A, Jørgensen LF, Whitehead D	2020	European Minerals Inventory as part of the Mineral Intelligence for Europe	GeoUtrecht2020, 21 – 26 Aug. 2020, online	DOI: 10.48380/dggv-e7rh-bs86	MINTELL4EU
Kumelj S, the FRAME Team	2019	MINTELL4EU -Inventory	Raw Materials Week 2019, 18 – 22 Nov 2019, Brussels, Belgium	Poster	MINTELL4EU
Kumelj Š, Vihtelič A, Hribernik K, Bavdek J	2020	Minerals Inventory as a part of Mineral Intelligence for Europe	EGU2020, 4 – 8 May 2020, online	https://doi.org/10.5194/egusphere-egu2020-17309	MINTELL4EU
Laskaridis K	2021	Contribution of the LITHOS Laboratory of EAGME	Marble Peak	https://www.marblepeak.gr/; https://www.facebook.com/marble.peak1/photos/a.168885872082845/171046171866815/	EuroLithos
Laskaridis K, Arapakou A, Patronis M, Kousseris I	2021	Physical mechanical properties and producing areas of Greek dimension stones	International Conference on Raw Materials and Circular Economy – RawMat2021, 05-09 Sept 2021, Athens, Greece	https://www.rawmat2021.gr/congress/	EuroLithos
Lobato A, Marino E, González FJ, Medialdea T, Somoza L	2021	Predicting potential areas for the formation of Co-rich ferromanganese crusts in the Canary Islands Seamount Province using multi-criteria GIS analysis.	EGU2021, 19 – 30 April 2021, online	https://doi.org/10.5194/egusphere-egu21-15563	MINDeSEA
Małek R, Mikulski SZ	2019	Geochemical-mineralogical research of the rare and associated element concentrations within cassiterite-sulphide mineralization in the Stara Kamienica schist belt In the Western Sudetes – preliminary results.	9th National Conference, 28 – 29.03.2019, Przeglad Geologiczny, 67(3): 179–182, Warsaw, Poland	doi: 10.7306/2019.14). (in Polish with English abstract)	FRAME

continuation table A 2

Author(s)	Year	Title	Conference / Workshop / Newspaper	ISSN/ URL / DOI	Project
Małek R, Mikulski SZ, Chmielewski A	2019	The geochemical-mineralogical characteristic of cassiterite-sulphide mineralization in the historic Saint John and Saint Leopold shafts in the Stara Kamienica shist belt (Western Sudetes),	9th National Conference, Przeglad Geologiczny, 67(11): 914-924, 852, Warsaw, Poland	doi: 10.7306/2019.50.(in Polish with English abstract)	FRAME
Marincea Ş, Dumitraş D G, Sava C	2019	Ludwigite within five occurrences of magnesian skarns from Romania: New mineralogical dat	Goldschmidt Conference 2019, 18 – 23 August 2019, Barcelona, Spain	https://www.eag.eu.com/events/goldschmidt/2019report/	FRAME
Marino E	2019	Las costras de hierro-manganeso con alto contenido en cobalto de los márgenes atlánticos de España: recursos minerales y fuente de elementos estratégicos	3º PhDay Complutense (Ciencias Geológicas)		MINDeSEA
Marino E, González FJ, Luna R, Somoza L, Medialdea T, Kuhn T, Wegorzewski A, Oeser M	2019	Hydrothermal Input in Fe-Mn Crusts from Canary Islands Seamount Province: LA-ICP-MS Analyses and Fe Isotopes	Goldschmidt Conference 2019, 18 – 23 August 2019, Barcelona, Spain	https://goldschmidtabstracts.info/2019/2153.pdf	MINDeSEA
Marino E, González FJ, Lunar R, Somoza L, Medialdea T, Reyes J, Kuhn T, Wegorzewski AV, Madureira P, Mirao J, Miguel C, Oeser M	2019	Ferromanganese crusts from the Canary Island Seamount Province: High-resolution tools for critical metals determination	Workshop "Marine E-Tech –Multidisciplinary Research on the Rio Grande Rise", 19 – 22 Nov 2019, Ubatuba, Brazil	https://coreiousp.wixsite.com/marine-e-tech	MINDeSEA
Marino E, González FJ, Lunar R, Somoza L, Reyes J, Medialdea T, Bellido E, Kuhn T, Wegorzewsk A, Oeser-Rabe M	2018	Mineralogy and geochemistry of critical metals in Fe-Mn crusts from the Canary Islands Seamount Province	Geological Society of London, Marine Minerals: A New Resource for the 21st Century, 31 Oct – 01 Nov 2018, London, United Kingdom	Marine Minerals: A New Resource for the 21st Century | SUT | Society for Underwater Technology	MINDeSEA
Marino E, González FJ, Medialdea T, Somoza L, Ferreira P, Kuhn T, Magalhaes V, Lobato A	2021	REY contents in Fe-Mn crusts in Macaronesia: evidence of variation with depth and mineralogy.	EGU2021, 19 – 30 April 2021, online	https://doi.org/10.5194/egusphere-egu21-15519	MINDeSEA
Marino E, González FJ, Medialdea T, Somoza L, Lunar R, Ferreira P, Kuhn T, Hein JR, Magalhaes V, Blasco I	2020	Hydrogenetic Fe-Mn crusts from European seas: source of potentially economic cobalt mining.	EGU2020, 4–8 May 2020, online	https://doi.org/10.5194/egusphere-egu2020-22091	MINDeSEA

continuation table A 2

Author(s)	Year	Title	Conference / Workshop / Newspaper	ISSN/ URL / DOI	Project
Marino E, González FJ, Somoza L, Kuhn T, Medialdea T, Madureira P, Lunar R	2020	Cobalt-rich Ferromanganese Crusts from the Canary Islands Seamounts: Mineralogy and Geochemistry of Strategic and Critical Elements.	Underwater Minerals Conference - 49th UMC 2020, 27 Sept – 2 Oct 2020, St. Petersburg, USA	https://www.underwaterminerals.org/_files/ugd/cacc41_da306712968f43e8b6196eb055815347.pdf	MINDeSEA
Marino E, González FJ, Somoza L, Kuhn T, Medialdea T, Oeser M, Lunar R	2020	REE contents in Fe-Mn crusts from Canary Island Seamount Province: High-resolution analysis to identify the metal- bearing minerals.	ERES2020, virtual conference	https://eres2020.eres-conference.eu/wp-content/uploads/2020/09/39.pdf	MINDeSEA
Marino E, González FJ, Somoza L, Medialdea T, Ferreira P, Kuhn T, Lobato A, Magalhaes V, Moniz C	2021	Discovering the high potential for critical raw materials of submarine Fe-Mn deposits in European seas: GIS multi criteria analysis on MINDeSEA database	International Conference on Raw Materials and Circular Economy – RawMat2021, 05 – 09 Sept 2021, Athens, Greece	https://www.rawmat2021.gr/congress/wp-content/uploads/2021/09/Program-final-RawMat2021-1.pdf	MINDeSEA
McGrath E, Workman T, Johnston D	2020	Tourism at Historic Mining Sites in Europe	GeoUtrecht2020, 21 – 26 Aug. 2020, online	DOI: 10.48380/dggv-rmyn-6y53	MINTELL4EU
Mikulski SM Brański P, Pieńkowski G, Małek R, Zglinicki K, Chmielewski P	2021	REE enrichment of sedimentary formations in selected regions of the Mesozoic margin of the Holy Cross Mountains – promising preliminary data and more research needed.	Przeglad Geologiczny, 69, 379–385	doi: 10.7306/2021.2, (in Polish with English abstract)	FRAME
Miletić S	2018	Geološka služba za Evropo (GeoERA) - Revija Mineral	Article on the GeoERA projects in the expert magazine "Mineral"	https://www.mineral-revija.si/1875/Geoloska-sluzba-za-Evropo-%28GeoERA%29	EuroLithos
Miletić S, Novak M	2021	O slovenskem naravnem kamnu u direktoriju evropskega kamna	Article in the proceedings of the 25. meeting of Slovenian geologists, 74-77	https://drive.google.com/file/d/1X08cxpBa-tOEu-mKuhJbK5iUMH4q3yMp/view?usp=sharing	EuroLithos
Millot R, Gourcerol B, Gloaguen E, Lefebvre G, Melleton M	2021	Relocaliser l'extraction des ressources minérales : en Europe, les défis du lithium,	The Conversation 2020, June 1, 2020 6.20pm BST - Updated August 4	https://theconversation.com/relocaliser-lextraction-des-ressources-minerales-en-europe-les-defis-du-lithium-138581	FRAME
Novak M	2021	Plenarno predavanje: 70 LET SLOVENSKEGA GEOLOŠKEGA DRUŠTVA	Presentation at the 25. meeting of Slovenian geologists	https://drive.google.com/file/d/1p4NtVQJ-DFz4OjdtDTuVq-Q0lZv139SwO/view	EuroLithos

continuation table A 2

Author(s)	Year	Title	Conference / Workshop / Newspaper	ISSN/ URL / DOI	Project
Pleiderer, S	2021	UNFC application to sand and gravel resources in an Austrian pilot area	UNECE Resource Management Week 2021 – 12th Session of the Expert Group on Resource Management. Enabling sustainability principles in resource management, 26 – 30 April 2021	https://unece.org/sed/documents/2021/04/presentations/unfc-application-sand-and-gravel-resources-austrian-pilot-area	MINTELL4EU
Reginuissen H, Jonsson E, Sánchez SMT, Diéz Montes A, Teran K, Salgueiro R, Filipe A, Inverno C	2020	FRAME: towards conflict-free Nb-Ta for the European Union.	EGU2020, 4 – 8 May 2020, online	https://doi.org/10.5194/egusphere-egu2020-10228	FRAME
Rincón-Tomás B, González FJ, Somoza L, Hein JR, Medialdea T, Santofimia E, Marino E, Madureira P	2021	Biomineralization processes in low-temperature, shallow-water hydrothermal vent at Tagoro submarine volcano, El Hierro Island (Central East Atlantic)	GeoKarlsruhe 2021, 19 – 23 Sep. 2021, online	https://www.conftool.pro/geokarlsruhe2021/index.php?page=-browseSessions&form_session=157#paperID425	MINDeSEA
Sadeghi M, Bertrand G, Decrée S, de Oliveira DPS	2020	Prospectivity mapping of phosphor in Europe; a part of the GEOERA-FRAME project	GeoUtrecht2020, 21 – 26. Aug. 2020, online	DOI: 10.48380-dggv-8z75-qg04	FRAME
Sadeghi M, Bertrand G, Reginuissen H, Arvanitidis N, Jonsson E, de Oliveira DPS	2020	Prospectivity mapping of phosphor in Europe; a part of the GEOERA-FRAME project	EGU2020, 4 – 8 May 2020, online	https://doi.org/10.5194/egusphere-egu2020-7931	FRAME
Sadeghi, M	2020	Prospectivity mapping of critical raw material at the continental scale - a part of the FRAME project	Mineral Exploration Symposium, 17 – 18. Sep. 2020, online	https://eage.eventsair.com/mineral-exploration-symposium/	FRAME
Sava C, Marincea, Ş Dumitraş DG, Iancu AM, Vanheyste J, Dal Bo, F	2019	Vesuvianite from the high-temperature skarn occurrences from Romania	Goldschmidt Conference 2019, 18 – 23 August 2019, Barcelona, Spain	https://www.eag.eu.com/events/goldschmidt/2019report/	FRAME
Scutelnicu I, Cetean V	2021	Limestone historical quarry from Magura Calanului		https://www.youtube.com/watch?v=13mxfVm-cC8	EuroLithos
Sievers H	2021	New raw materials from old mines? – Examples from historic mining sites in Europe	GeoKarlsruhe 2021, 19 – 23 Sep. 2021, online	https://www.conftool.pro/geokarlsruhe2021/sessions.php	FRAME
Sievers H, Rambousek P, Serra M, Wittenberg A, Oliveira D	2020	Raw Material Potential from Historic Mine Sites	GeoUtrecht2020, 21 – 26. Aug. 2020, online	DOI: 10.48380/dggv-ty6z-wx98	FRAME

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Author(s)	Year	Title	Conference / Workshop / Newspaper	ISSN/ URL / DOI	Project
Sievers H, Wittenberg A, Oliveira D	2019	Historic mine sites revisited	GeoMünster2019, 22 – 25. Sep. 2019, Münster, Germany	http://www.geomuenster2019.de/assets/geomuenster_book_of_abstracts.pdf	FRAME
Sievers, H	2020	Historic mine sites revisited	AIMS2020, 2-3 April 2020, online	DOI: 10.18154/RWTH-2020-03831, https://publications.rwth-aachen.de/record/786983/files/786983.pdf	FRAME
Šinigoj J, Miletić S, Kumelj Š, Teran K, Burger A, Rokavec D	2018	Ge. oška služba za Evropo	Mineralne Surovine v letu, GeoZS, 8	ISSN 1854-293X	GeoERA
Solberg JK, Gautneb H		UNFC Case Study on Graphite	Raw Materials Week 2020: UNFC Europe: Ensuring sustainable raw material management to support the European Green Deal. Virtual Workshop Nov. 19, 2020	https://unece.org/sustainable-energy/events/virtual-workshop-unfc-europe-ensuring-sustainable-raw-material-management	MINTELL4EU
Somoza, L	2018	El interés (la lucha) por los Recursos Energéticos y Minerales de los Océanos: desde el Ártico a la Antártida	Madrid Navy Week	Tríptico Foro de Pensamiento Naval ETSI.pdf (upm.es)	MINDeSEA
Teran, K	2020	Critical Raw Materials (CRM) potential of Slovenian historical mining sites	GeoUtrecht2020, 21 – 26. Aug. 2020, online	DOI: 10.48380/dggv-fjcw-tp10	FRAME
The GeoERA Raw Materials Team	2019	GeoERA-Raw Materials	Prospectors & Developers Association of Canada (PDAC 2019)	https://www.pdac.ca/	GoERA Raw Materials
The GeoERA Raw Materials Team	2020	GeoERA-Raw Materials	Prospectors & Developers Association of Canada (PDAC 2020)	https://www.pdac.ca/	GoERA Raw Materials
The GeoERA Raw Materials Team	2021	GeoERA-Raw Materials	Prospectors & Developers Association of Canada (PDAC 2021)	https://www.pdac.ca/	GoERA Raw Materials
Whitehead D, Jørgensen LF, Pedersen M, Brown T, Kumelj Š, Aasly KA, Clain U	2020	Mintell4EU – Mineral Intelligence for Europe – a GeoERA project to improve and sustain the European raw materials knowledge base	EGU2020, 4 – 8 May 2020, online	https://doi.org/10.5194/egusphere-egu2020-16935	MINTELL4EU
Wittenberg A	2019	Thoughts on chances and hurdles UNFC and UNRM	5. Meggener Rohstofftage, 11 – 13. Sept. 2019, Lennestadt-Meggen, Germany	https://elvis/fsc/fscasp/content/bin/fscvext.dll?mx=COO.2164.100.2.2203622; https://elvis/fsc/fscasp/content/bin/fscvext.dll?mx=COO.2164.100.2.2139787	GeoERA Raw Materials

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Author(s)	Year	Title	Conference / Workshop / Newspaper	ISSN/ URL / DOI	Project
Wittenberg, A	2018	GeoERA - European Geological Surveys joint action to improve Data Management	CRM Data Management Workshop, 26. Nov 2018 BAM, Berlin, Germany	http://scale-project.eu/wp-content/uploads/2018/12/9-A.-Wittenber-A.-Maul_GeoERA.pdf	GeoERA Raw Materials
Wittenberg A	2021	UNFC and UNRMS in the spotlight of the GeoERA perspective	UNECE Resource Management Week 2021 - 12th Session of the Expert Group on Resource Management. Enabling sustainability principles in resource management, 26 – 30 April 2021	https://unece.org/sed/documents/2021/04/presentations/unfc-and-unrms-spotlight-geoera-perspective-antje-wittenberg	MINTELL4EU
Wittenberg A, de Oliveira DPS, González Sanz FJ, Heldal T, Whitehead D, Flindt Jørgensen L	2021	GeoERA Raw Materials supporting Europe's mining future	AIMS2020, 2-3 April 2020, online	10.18154/RWTH-2020-03831 ; https://publications.rwth-aachen.de/record/786983/files/786983.pdf	GeoERA Raw Materials
Wittenberg A, González Sanz FJ, de Oliveira DPS, Tulstrup J, Heldal T	2018	GeoERA´s interest in earth observation data	Raw Materials Week 2018, 12-16 November 2018, Brussels, Belgium	https://ec.europa.eu/growth/content/raw-materials-week-2018_en; https://ec.europa.eu/docsroom/documents/32882/attachments/5/translations/en/renditions/native	GeoERA Raw Materials
Wittenberg A, González Sanz FJ, Oliveira DPS, Jørgensen LF, Heldal T	2020	Mineral resources - crucial components of a vital and wealthy society	EGU2020, 4 – 8 May 2020, online	https://doi.org/10.5194/egusphere-egu2020-7947	GeoERA Raw Materials
Wittenberg A, Oliveira D, Heldal T, González FJ, Jørgensen LF	2019	GeoERA – Geological Survey Organisations contribution to Europe's raw materials sustainability	GeoMünster2019, 22 – 25. Sep. 2019, Münster, Germany	http://www.geomuenster2019.de/assets/geomuenster_book_of_abstracts.pdf	GeoERA Raw Materials
Wittenberg A, Oliveira DPS, Jørgensen LF, González FJ, Sievers H, Quental L, Pereira A, Heldal T, Whitehead D	2020	Raw materials - you can't do well without them	GeoUtrecht2020, 21 – 26 Aug. 2020, online	DOI: 10.48380/dggv-e6s1-zz36	GeoERA Raw Materials
Wittenberg A, Oliveira DPS, González Sanz FJ, Jørgensen LF, Heldal T	2021	GeoERA´s Contribution Towards Resilience in Europe's Raw Materials Supply Chains	EGU2021, 19 – 30 April 2021, online	doi: 10.5194/egusphere-egu21-15047	GeoERA Raw Materials
Wittenberg A, Oliveira DPS, González Sanz FJ, Jørgensen LF, Heldal T	2021	GeoERA Raw Materials to support Europe's resilience on Raw Materials	SGA News 48, March 2021	https://e-sga.org/fileadmin/sga/newsletter/news_48/SGANews48_low.pdf	GeoERA Raw Materials

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Author(s)	Year	Title	Conference / Workshop / Newspaper	ISSN/ URL / DOI	Project
Wittenberg A, Oliveira DPS, González Sanz J, Jørgensen LF, Whitehead D, Heldal T	2020	Mineral resources - crucial components of a vital and wealthy society	EGU2020, 4 – 8 May 2020, online	https://doi.org/10.5194/egusphere-egu2020-7947	GeoERA Raw Materials
Wittenberg A, Oliveira DPS, Heldal T, González Sanz FJ, Jørgensen LF	2019	GeoERA- Geological Survey Organisations contribution to Europe's raw materials sustainability	GeoMünster2019, 22 – 25. Sep. 2019, Münster, Germany	http://www.geomuenster2019.de/assets/geomuenster_book_of_abstracts.pdf	GeoERA Raw Materials
Wittenberg A, Oliveira DPS, Jørgensen LF, Heldal T, González San FJ	2021	Europe's resilience on raw materials – how did GeoERA contribute.	GeoKarlsruhe 2021, 19 – 23 Sep. 2021, online	https://www.conftool.pro/geokarlsruhe2021/index.php?page=browseSessions&form_session=200#papeRID290	GeoERA Raw Materials
Wittenberg A, the GeoERA Raw Materials Team	2019	Actions Towards Europe´s Raw Materials Sustainability	Raw Materials Week 2019, 18 – 22 Nov 2019, Brussels, Belgium	Poster	GeoERA Raw Materials
Wittenberg A, Tulstrup J, de Oliveira DPS González Sanz	2019	Taking the next steps	Final event of the ORAMA project - Next steps in improving European RM data, 22.11.2019, Brussels, Belgium	https://orama-h2020.eu/ https://orama-h2020.eu/wp-content/uploads/ORAMA_final_event_GeoERA.pdf	GeoERA Raw Materials
Wittenberg A	2019	GeoERA contribution to the front-end of strategic value chains	ORAMA & JRC RMIS Joint Workshop: Data Optimization for Primary & Secondary Raw Materials, 13.06.2019, Ispra	https://elvis/fsc/fscasp/content/bin/fscvext.dll?mx=COO.2164.100.2.2160620	GeoERA Raw Materials
Wittenberg A	2018	GeoERA, and other Member States projects on raw materials	Raw Materials Week 2018, 12 – 16 November 2018, Brussels, Belgium	https://ec.europa.eu/docsroom/documents/32889; https://ec.europa.eu/growth/content/raw-materials-week-2018_en	GeoERA Raw Materials
Wittenberg, A and the GeoERA Raw Materials Team	2021	UNFC and UNRMS in the spotlight of the GeoERA perspective.	Resource Management Week 2021, 26 – 30 April 2021, Geneva, Switzerland	https://unece.org/sed/documents/2021/04/presentations/unfc-and-unrms-spotlight-geoera-perspective-antje-wittenberg	GeoERA Raw Materials
Zalba I, González FJ, Fernández-Puga MC, Nyberg J	2021	Ferromanganese concretions in the Baltic Sea: characterization and forming processes.	10th Geological Congress of Spain, 5 – 7 July 2021, Vitoria-Gasteiz, Spain	https://geo3bcn.csic.es/index.php/news-events/news/1845-geo3bcn-researchers-will-participate-in-the-xth-spanish-geological-congress?jjj=1650365615787	MINDeSEA
Zananiri I, the MINDeSEA Team	2018	Η ΣΥΜΜΕΤΟΧΗ ΤΟΥ ΙΓΜΕ ΣΤΟ ΕΥΡΩΠΑΙΚΟ ΠΡΟΓΡΑΜΜΑ GeoERA: Θεματικό πεδίο ΠΡΩΤΕΣ ΥΛΕΣ	Thessaloniki International Fair 2018	83rd Thessaloniki International Fair 2018 (greeknewsagenda.gr)	MINDeSEA

Table A 3: *List of GeoERA Raw Materials Project Newsletters*

Author(s)	Project Newsletter	Issue	Date	URL
Teresa Calabaça et al.	FRAME	Issue 1	October 2018	http://www.frame.lneg.pt/wp-content/uploads/2018/10/FRAME-Newsletter-Issue-1.pdf
Teresa Calabaça et al.	FRAME	Issue 2	February 2019	http://www.frame.lneg.pt/wp-content/uploads/2019/02/FRAME-Newsletter-Issue-2.pdf
Teresa Calabaça et al.	FRAME	Issue 3	June 2019	http://www.frame.lneg.pt/wp-content/uploads/2019/06/FRAME-Newsletter-Issue-3.pdf
Teresa Calabaça et al.	FRAME	Issue 4	October 2019	http://www.frame.lneg.pt/wp-content/uploads/2019/10/GeoERA_FRAME-Newsletter-Issue-4.pdf
Teresa Calabaça et al.	FRAME	Issue 5	February 2020	http://www.frame.lneg.pt/wp-content/uploads/2020/04/GeoERA_FRAME-Newsletter-Issue-5.pdf
Teresa Calabaça et al.	FRAME	Issue 6	June 2020	http://www.frame.lneg.pt/wp-content/uploads/2020/06/FRAME-Newsletter-Issue-6.pdf
Calabaça T et al.	FRAME	Issue 7	October 2020	http://www.frame.lneg.pt/wp-content/uploads/2020/10/FRAME-Newsletter-Issue-7.pdf
Calabaça T et al.	FRAME	Issue 8	June 2021	http://www.frame.lneg.pt/wp-content/uploads/2021/06/FRAME-Newsletter-Issue-8.pdf
Calabaça T et al.	FRAME	Issue 9	October 2021	http://www.frame.lneg.pt/wp-content/uploads/2021/11/FRAME-Newsletter-Issue-9.pdf
Liinamaa-Dehls A	EuroLithos	No. 3	2020	https://www.eurolithos.org/_files/ugd/2b8de6_9350d523867644a18f14c85485b76036.pdf
Liinamaa-Dehls A	EuroLithos	No. 4	2021	https://www.eurolithos.org/_files/ugd/2b8de6_7c9cb5eb21-b84a7caa2ad1557b320f53.pdf
Liinamaa-Dehls A	EuroLithos	No. 5	2021	https://www.eurolithos.org/copy-of-may-2019-1
Liinamaa-Dehls A	EuroLithos	No. 1	2019	https://www.eurolithos.org/_files/ugd/2b8de6_d0b8e0384b114f7896-ec5e3d360e95c4.pdf
Liinamaa-Dehls A	EuroLithos	No. 2	2019	https://www.eurolithos.org/_files/ugd/2b8de6_87fb34460ae648d888-af551df544ecbd.pdf
González FJ	MINDeSEA	Newsletter 1	August 2018	https://69ef338c-adbf-4a98-94a6--1e32d03179fa.filesusr.com/ugd/e60895_25072150f07149-af9ccd81ca5e5ddf5f.pdf
González FJ	MINDeSEA	Newsletter 2	December 2018	https://69ef338c-adbf-4a98-94a6-1e32d03179fa.filesusr.com/ugd/e60895_9489c8890c6643d09c490814c47d7cd2.pdf

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Author(s)	Project Newsletter	Issue	Date	URL
González FJ	MINDeSEA	Newsletter 3	August 2019	https://69ef338c-adbf-4a98-94a6-1e32d03179fa.filesusr.com/ugd/e60895_317868c58689487d9fd730bf4cb2fd29.pdf
González FJ	MINDeSEA	Newsletter 4	December 2019	https://69ef338c-adbf-4a98-94a6-1e32d03179fa.filesusr.com/ugd/e60895_a256b93b95bf45cc9fd23-ff3e975630f.pdf
Wittenberg A, the GeoERA Raw Materials Team	Special issue about the Raw Materials Week	GeoERA Newsletter #10,	25. November 2019	https://mailchi.mp/a75281f2cc6a/geoera-newsletter-4729029?e=-d25833d8a9

Table A 4: *List of GeoERA Raw Materials scientific project deliverables of scientific/technical relevance. Not provided any deliverables elated to administrative and management issues. In alphabetic order of first author.*

Author(s)	Year	Title	Deliverable	URL	Project
Arvanitidis N, Gautneb H, Jonsson E, Lynch E, Reginiussen H, Sadeghi M	2018	Producing a report describing the methodology used for the identification and selection process of the CRM to be included in the metallogenetic map	D3.1, 84 p.	http://geoera.eu/wp-content/uploads/2018/10/FRAME_D3.1-1.pdf	FRAME
Bahar B, Kumelj Š, Vihtelič A	2021	Deliverable 3.3 – Quality control system for harvesting report	D3.3, 17 p.	https://geoera.eu/wp-content/uploads/2021/10/D3.3-Quality-control-system-for-harvesting-report.pdf	MINTEL-L4EU
Carvalho J, Carvalho C, Lisboa V	2021	Eurolithos Atlas - Portugal	131 p.	https://repository.europe-geology.eu/egdidocs/eurolithos/eurolithos+atlas+portugal.pdf	EuroLithos
Carvalho J, Heldal T	2019	Summary on the nature and type of available spatial data in each country partner and framework for the Atlas	D3.1., 34 p.	https://www.eurolithos.org/_files/ugd/2b8de6_2e98c02b99b14ba19f5cf620d83db61f.pdf	EuroLithos
Carvalho J, Heldal T, Hadjigeorgiou G, Hadjigeorgiou C, de Nardo MT, Laskaridis K, Arapakou A, Lucarini M, Fumanti F, Miletić S, Novak M	2020	Country-level atlases and a European Atlas of Ornamental Stones. Printed and digital versions	D3.3, 62 p.	https://www.eurolithos.org/_files/ugd/2b8de6_1cb3afa8fde14250-994511d8e400fc4f.pdf	EuroLithos
Carvalho J, Lisboa JV	2021	Eurolithos case study, Sustainable exploitation of ornamental limestones in Maciço Calcário Estremenho, Portugal	D5.1, 17 p.	https://www.eurolithos.org/_files/ugd/2b8de6_4763ea178b6c45d7b5f49e847a8c28fd.pdf	EuroLithos
Carvalho JMF, Heldal T	2020	D3.2 Country-level and European-level Atlas templates for input of harmonized data	D3.2, 57 p.	https://www.eurolithos.org/_files/ugd/2b8de6_69db44e8bc444d44a68fb598646381 07.pdf	EuroLithos
Cetean V, Peţan A	2021	Eurolithos case study, Magura Calanului - Heritage assessment of historical quarry	D5.1, 17 p.	https://repository.europe-geology.eu/egdidocs/eurolithos/magura+calanului+-+heritage+assessment+of+historic.pdf	EuroLithos
de Nardo MT	2021	EuroLithos Atlas – Emilia-Romagna	D3.3, 64 p.	https://repository.europe-geology.eu/egdidocs/eurolithos/eurolithos+atlas_emrom.pdf	EuroLithos
Deady E, Kumelj Š, Idoine N, Passmore J, Brown T	2021	Deliverable 2.1 – Report describing the processes developed for updating the electronic European Minerals Yearbook	D2.1, 22 p.	https://geoera.eu/wp-content/uploads/2021/11/D2.1-Electronic-European-Minerals-Yearbook.pdf	MINTEL-L4EU

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Author(s)	Year	Title	Deliverable	URL	Project
Dedić Z, Horvat M, Brčić V	2021	Eurolithos case study, Heritage assessment of quarry landscapes: Quarries near Pučišća, the island of Brač, Croatia	D5.1, 21 p.	https://repository.europe-geology.eu/egdidocs/eurolithos/heritage+assessment+of+quarry+landscapes-+quarries.pdf	EuroLithos
Dedić Z, Nikolina Ilijanić N	2021	Eurolithos case study, The Pučišća Stonemason School	D5.1, 15 p.	https://repository.europe-geology.eu/egdidocs/eurolithos/the+pucisca+stonemason+school.pdf	EuroLithos
Dedić Z, Heldal T, Carvalho J, Cetean V, Hadjigeorgiou C, Martínez Martínez J, Lucarini L, Trajanova M	2020	EuroLithos case study collection	D5.1., 25 p.	https://repository.europe-geology.eu/egdidocs/eurolithos/eurolithos-d51_hgi-cgs.pdf	EuroLithos
Ferreira P, Moniz C, González FJ, Nyberg J, Kuhn T, Ruehlemann C, Marino E, Melnyk I, Malyuk B, Magalhães V	2021	Deliverable 6.2: Report of the polymetallic nodules prospect evaluation parameters that will be employed as a road map for the creation of the polymetallic nodules occurrence database	D.6.2, 52 p.	https://geoera.eu/wp-content/uploads/2021/06/MINDeSEA_D6-2_WP6-Polymetallic-nodules-prospect-evaluation-parameters.pdf	MINDeSEA
Ferreira P, Moniz C, González FJ, Nyberg J, Kuhn T, Ruehlemann C, Marino E, Melnyk I, Malyuk B, Magalhães V	2021	Deliverable 6.3 – Database and maps on polymetallic nodules	D 6.3, 4 p.	https://geoera.eu/wp-content/uploads/2021/11/MINDeSEA_D6-3_WP6-Database-and-maps-on-polymetallic-nodules.pdf	MINDeSEA
Ferreira P, Moniz C, González FJ, Nyberg J, Kuhn T, Ruehlemann C, Marino E, Melnyk I, Malyuk B	2021	Deliverable 6.5: Report of the polymetallic nodules prospect evaluation for European waters based on data generated by this study	D 6.5, 36 p.	https://geoera.eu/wp-content/uploads/2021/11/MINDeSEA_D6-5_WP6-Polymetallic-nodules-potentiality-and-predictivity.pdf	MINDeSEA
Ferreira P, Moniz, C, González FJ, Nyberg J, Kuhn T, Rühlemann C, Marino E, Melnyk I, Malyuk B, Magalhães V	2021	Deliverable 6.4 – Polymetallic Nodules Potenciality and Predictivity Map	D 6.4, 1 map	https://geoera.eu/wp-content/uploads/2021/11/MINDeSEA_D6-4_WP6-Mineral-potential-and-prospectivity-map-of-polymetallic-nodules.jpg	MINDeSEA
Ferreira P, Moniz C, González FJ, Nyberg J, Kuhn T, Rühlemann C, Marino E, Melnyk I, Malyuk B, Magalhães V	2021	Deliverable 6.4 – Metallogenic Map of Polymetallic Nodules Occurrences in pan-European Seas	D 6.4, 1 map	https://geoera.eu/wp-content/uploads/2021/11/MINDeSEA_D6-4_WP6-Metallogenic-map-of-polymetallic-nodules.jpg	MINDeSEA
Gautneb H, Gloaguen E, Törmänen T	2020	Develop and/or review models for the formation of natural graphite, lithium, and cobalt in Europe	D5.2, 63 p.	- not public -	FRAME

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Author(s)	Year	Title	Deliverable	URL	Project
Gautneb H, Gloaguen E, Törmänen T	2021	Energy critical elements and minerals in Europe; occurrence, types, characteristics, formation, and future potential for European production (part 1 report)	D5.3, 54 p.	- not public -	FRAME
Gautneb H, Gloaguen E, Törmänen T, Bertrand G, Sadeghi M, Schedl A, Pfleiderer S, Negulescu E	2019	Provide mineral potential and prospectivity maps of key mineral provinces in Europe with deposits of, or potential for, energy critical elements (natural graphite, lithium, cobalt) in collaboration with WP 3	D5.1, 60 p.	- not public -	FRAME
Gautneb H, Gloaguen E, Törmänen T, Pereira A, Sadeghi M	2021	Map of Cobalt, graphite, lithium deposits (including deposits where cobalt is a significant by product)	D5.4, 8 p.	- not public -	FRAME
Gautneb H, Gloaguen E, Törmänen T, Pereira A, Sadeghi M	2021	Relevant metallogenetic maps	D5.5, 8 p.	- not public -	FRAME
González and The MINDeSEA Team	2021	Deliverable 4.2 – Database and maps on ferromanganese crusts and phosphorites	D 4.2; 5 p.	https://geoera.eu/wp-content/uploads/2021/11/MINDeSEA_D4-2_WP4-Database-and-maps-on-ferromanganese-crusts-and-phosphorites.pdf	MINDeSEA
González FJ, Blasco I, Blanco L, Marino E, Somoza L, Medialdea T, Ferreira P, Magalhães V	2018	First compilation map of "Energy-Critical Elements" in pan-European seas: ferromanganese deposits	D1.1, 1 map	https://geoera.eu/wp-content/uploads/2019/10/MINDeSEA_WP1_MINDeSEA_-D1-1-Annex_Pan-European-Map-of-Submarine-%E2%80%9CEnergy-Critical-Elements%E2%80%9D-v1.pdf	MINDeSEA
González FJ, Marino E, Lobato A, Somoza L, Medialdea T	2021	Deliverable 4.7: Case study for ferromanganese crusts and phosphorites in the Macaronesia area (NE Atlantic Ocean). GeoERA-MINDeSEA project	D 4.7, 20 p.	https://geoera.eu/wp-content/uploads/2021/11/MINDeSEA_D4-7_WP4-Results-of-the-case-study.pdf	MINDeSEA
González FJ, Marino E, Somoza L, Medialdea T, Lobato A, Blasco I, Kuhn T, Ruehlemann C, Ferreira P, Alcorn T, Magalhães V, Hein JR, Cherkashov G	2021	Deliverable 4.4 - Models of formation for the main provinces of ferromanganese crusts and phosphorites - Metallogenic Map of Ferromanganese Crust and Phosphorite Occurrences in panEuropean Seas	D4.4, 5 p.	https://geoera.eu/wp-content/uploads/2021/06/MINDeSEA_D4-4_WP4-Fe-Mn-crusts-and-phosphorites-metallogenic-map_reportmap.pdf	MINDeSEA

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Author(s)	Year	Title	Deliverable	URL	Project
González FJ, Marino E, Somoza L, Medialdea T, Lobato A, Blasco I, Kuhn T, Ruehlemann C, Ferreira P, Alcorn T, Magalhães V, Hein JR, Cherkashov G	2021	Deliverable 4.4 – Models of formation for the main provinces of ferromanganese crusts and phosphorites	D4.4, 67 p.	https://geoera.eu/wp-content/uploads/2021/06/MINDeSEA_D4-4_WP4-Fe-Mn-crusts-and-phosphorites-metallogenic-models.pdf	MINDeSEA
González FJ, Marino E, Somoza L, Medialdea T, Lobato A, Blasco I, Kuhn T, Ruehlemann C, Ferreira P, Alcorn T, Magalhães V, Hein JR, Cherkashov G	2021	Deliverable 4.5 – Exploration potential of CRM associated with submarine ferromanganese crusts and phosphorites in Europe	D 4.5, 36 p.	https://geoera.eu/wp-content/uploads/2021/11/MINDeSEA_D4-5_WP4-Fe-Mn-crusts-and-phosphorites-exploration-potential.pdf	MINDeSEA
González FJ, Marino E, Somoza L, Medialdea , Lobato A, Blasco I, Kuhn T, Ruehlemann C, Ferreira P, Alcorn T, Magalhães V, Hein JR, Cherkashov G	2021	Deliverable 4.3 – Ferromanganese Crusts and Phosphorites Pan-European Predictivity Map	D 4.3; 1 map	https://geoera.eu/wp-content/uploads/2021/11/MINDeSEA_D4-3_WP4-Predicitivity-map-of-Fe-Mn-crusts-and-phosphorites.jpg	MINDeSEA
González FJ, Marino E, Somoza L, Medialdea T, Lobato A, Blasco I, Kuhn T, Ruehlemann C, Ferreira P, Alcorn T, Magalhães V, Hein JR, Cherkashov G	2021	Deliverable 4.3 – Ferromanganese Crust and Phosphorites Potentiality Map	D4.3; 1 map	https://geoera.eu/wp-content/uploads/2021/11/MINDeSEA_D4-3_WP4-Potential-map-of-Fe-Mn-crusts-and-phosphorites.jpg	MINDeSEA
González FJ, Zalba I, Somoza L, Medialdea T, Marino E, Lobato A, Kuhn T, Ruehlemann C, Ferreira P, Magalhães V, Hein JR, Cherkashov G	2021	Deliverable 4.6: Present-day status of regulation, legislation and exploitation on Deep Sea Mining activities	D 4.6, 50 p.	https://geoera.eu/wp-content/uploads/2021/11/MINDeSEA_D4-6_WP4-Status-of-regulation-legislation-and-exploitation.pdf	MINDeSEA
GSB, LNEG, CGS, NGU, GSE	2020	Overview of the phosphate deposits and occurrences in Europe under the form of a database and map(s)	D4.2, 18 p.	- not public -	FRAME
GSB, LNEG, CGS, NGU, GSE	2020	New mineralogical and geochemical data on samples from phosphate deposits/occurrences	D4.2, 21 p.	- not public -	FRAME
GSB, LNEG, CGS, NGU, GSE	2020	Detailed metallogenic studies of key phosphate deposits in Europe	D4.3, 52 p.	- not public -	FRAME

continuation table A 4

Author(s)	Year	Title	Deliverable	URL	Project
GSB, LNEG, NGU	2021	Development of a procedure to prepare and analyze phosphate deposits with the objective to provide internally consistent geochemical data at a European level for this type of mineralization	D4.4, 29 p.	- not public -	FRAME
Hadjigeorgiou C	2021	Eurolithos case study, Built heritage of Nicosia, Cyprus: the use of calcarenite as built stone from antiquity to recent times	D5.1, 34 p.	https://www.eurolithos.org/_files/ugd/2b8de6_891595a9cfd848e3b68fce20a4956c5d.pdf	EuroLithos
Hadjigeorgiou G, Hadjigeorgiou C	2021	EuroLithos Atlas – Cyprus	D3.3, 112 p.	https://repository.europegeology.eu/egdidocs/eurolithos/eurolithos+atlas_cyprus.pdf	EuroLithos
Heldal T	2021	Eurolithos case study, The use of traditional crafts in the production of the Oppdal Schist, South-Central Norway	D5.1, 20 p.	https://repository.europe-geology.eu/egdidocs/eurolithos/the+use+of+traditional+crafts+in+the+production+of.pdf	EuroLithos
Heldal T	2021	The Iddefjord granite quarry landscape	D5.1, 26 p.	https://www.eurolithos.org/_files/ugd/2b8de6_bc6e5fe79fba48f087dc81a3ff5942d9.pdf	EuroLithos
Heldal T	2021	Evaluation of IP prototypes	D 6.2, 4 p.	https://www.eurolithos.org/_files/ugd/2b8de6_b831d0954e2d4178b75c1e7bf6842499.pdf	EuroLithos
Heldal T	2021	Eurolithos Atlas - Norway	D3.3, 256 p.	https://repository.europegeology.eu/egdidocs/eurolithos/eurolithos+atlas+norway.pdf	EuroLithos
Heldal T, Carvalho J, Laskaridis K	2019	Data and information structure for the knowledge platform on European ornamental stone resources	D6.1, 15 p.	- not public -	EuroLithos
Heldal T, Dedić Z	2021	Guidelines for assessing non-economic values of ornamental stone resources	D5.2 – 5.4, 11 p.	https://repository.europe-geology.eu/egdidocs/eurolithos/d+52+-+54+eurolithos.pdf	EuroLithos
Heldal T, Fromreide Nesheim H	2021	UNFC and ornamental stone resources – Larvikite case study	D6.6, 16 p.	https://repository.europegeology.eu/egdidocs/eurolithos/deliverable+d6-3.pdf	EuroLithos

continuation table A 4

Author(s)	Year	Title	Deliverable	URL	Project
Heldal T, Mølmann K	2021	Eurolithos case study, Connecting stone in constructions with stone resources: a technical case study	D5.1, 16 p.	https://www.eurolithos.org/_files/ugd/2b8de6_1ef129f1ae5e42a484d3774993e65e2b.pdf	EuroLithos
Hokka J, Eilu P, Schjøth F and Aasly KA	2021	Deliverable 4.2 – Report on harmonization issues, data gaps and challenges, reviewing also the quality of Pan-European aggregated inventories for selected commodities	D4.2, 22 p.	https://geoera.eu/wp-content/uploads/2021/10/D4.2-UNFC-Harmonisation-issues-gaps-and-recommendations.pdf	MINTELL4EU
Jørgensen LF, Deady E, Kumelj Š, Aasly KA, Urvois M, Pedersen M, Schjøth F, Tulstrup J	2021	Deliverable 1.3 Final – Project management report.	D1.3, 21 p.	https://geoera.eu/wp-content/uploads/2021/11/D1.3-Final-Project-management-report.pdf	MINTELL4EU
Kumelj Š, Bahar B, Vihtelič A, Hribernik K, Schjøth F, Heijboer T, Whitehead D, Pedersen M	2021	Deliverable 3.1 – Minerals Inventory Report.	D3.1, 27 p.	https://geoera.eu/wp-content/uploads/2021/11/D3.1-Mineral-Inventory-Report-Final.pdf	MINTELL4EU
Laskaridis K, Arapakou A	2021	Eurolithos Atlas – Greece	D3.3 580 p.	https://repository.europegeology.eu/egdidocs/eurolithos/eurolithos+atlas_greece_final.pdf	EuroLithos
Laskaridis K, Heldal T	2021	Working version on the directory containing information from selected countries and Guideline for using the Directory.	D4.1. – D4.2, 38 p.	https://www.eurolithos.org/_files/ugd/2b8de6_0eb1a71825d34acb8d2f1cc0013e5387.pdf	EuroLithos
Lucarini M, Fumanti F	2021	Eurolithos Atlas – Italy	D3.3, 46 p.	https://repository.europegeology.eu/egdidocs/eurolithos/eurolithos+atlas_italy.pdf	EuroLithos
Medialdea T, Zalba I, González FJ, Marino E, Somoza L, Lobato A, Blasco I, Schiellerup H, Zananiri I, Ferreira P, Monteys X, Alcorn T, Kuhn T, Ruehlemann C, Nyberg J,Malyuk B, Magalhães V, Lunar R, Hein JR, Cherkashov G	2021	Deliverable 2.4 – Report summarizing the resources of the project partners to disseminate information	D2.4, 64 p.	https://geoera.eu/wp-content/uploads/2021/11/MINDeSEA_D2-4_WP2-Dissemination-Products.pdf	MINDeSEA
Medialdea T, González FJ	2019	Deliverable 2.3 – Workshops dedicated to the main themes of the work packages	D2.3-1, 20 p.	https://geoera.eu/wp-content/uploads/2019/10/MINDeSEA_D2-3-1_WP2-Workshop-Report.pdf	MINDeSEA
Medialdea T, González FJ	2020	Deliverable 2.3 – Workshops dedicated to the main themes of the work packages	D2.3-4, 102 p.	https://geoera.eu/wp-content/uploads/2021/11/MINDeSEA_D2-3-4_WP2-Workshop-Report.pdf	MINDeSEA

continuation table A 4

Author(s)	Year	Title	Deliverable	URL	Project
Medialdea T, González FJ	2021	Deliverable 2.3 – Workshops dedicated to the main themes of the work packages	D2.3-5, 117 p.	https://geoera.eu/wp-content/uploads/2021/11/MINDeSEA_D2-3-5_WP2-Workshop-Report.pdf	MINDeSEA
Medialdea T., González FJ	2018	Deliverable 2.1: WP2 Dissemination and Exploitation Plan	D2.1, 17 p.	https://geoera.eu/wp-content/uploads/2019/10/MINDeSEA_D2-1_WP2-Communication-Dissemination-and-Exploitation-Plan_final.pdf	MINDeSEA
Miletić S, Novak M	2021	EuroLithos Atlas – Slovenia	D3.3, 232 p.	https://repository.europegeology.eu/egdidocs/eurolithos/eurolithos+country+atlas_slovenia.pdf	EuroLithos
Novak M, Miletić S	2021	Eurolithos case study; Best practices of natural stone valorisation for the preservation of stone-built heritage: the case of platy limestone as characteristic element of cultural landscape along the Eastern Adriatic coast	D5.1, 19 p.	https://www.eurolithos.org/_files/ugd/2b8de6_9436ba72b3a545448a747d799e758da4.pdf	EuroLithos
Pereira A, Quental L	2021	Final compilation of data and delivery to central GeoERA IP	D8.4, 29 p.	- not public -	FRAME
Quental L, Pereira A	2021	Assist in the data planning for the raw materials under study	D8.3, 19 p.	- not public -	FRAME
Quental L, Pereira A, Filipe Santos, de Oliveira D, Sadeghi M, Gautneb H, Gloaguen E, Törmänen T, Reginiussen H, Sievers H	2019	Deliver, in conjunction with the central GeoERA Information Platform, a norm for data format and delivery	D8.1, 16 p.	- not public -	FRAME
Reginiussen H, Jonsson E, Jonathan Hamisi, Sánchez SMT, Díez Montes a, Teran K, Rute Salgueiro R, Oliveira D, Inverno C, Augusto Filipe	2021	Nb-Ta mineralisation in sub-Saharan Africa, conflict mineral issues, and the possibilities for relieving European import dependence: a review and discussion	D6.3, 94 p.	- not public -	FRAME
Reginiussen H, Jonsson E, Sánchez SMT, Díez Montes A, Teran K, Pučko E, Salgueiro R, Oliveira D, Inverno C, Filipe A, Melnyk I, Bertrand G	2020	Outline of the exploration potential for Nb-Ta in Europe	D6.2, 102 p.	- not public -	FRAME

continuation table A 4

Author(s)	Year	Title	Deliverable	URL	Project
Reginiussen H, Jonsson E, Sánchez SMT, Díez Montes A, Teran K, Salgueiro R, Oliveira D, Inverno C, Filipe A, Melnyk I	2020	Distribution and systematics of Nb-Ta mineralisations in Europe	D6.1, 217 p.	- not public -	FRAME
Sadeghi M, Bertrand G, Arvanitidis n, de Oliveira D, Gautneb H, Gloaguen E, Törmänen T, Reginiussen H, Decree S, Pereira A, Quental L, Lynch E, Eoin McGrath, Delgado Arenas P, Sánchez SMT, Teran K, Munteanu M, Zoltán Horváth, Jonsson E, Rute Salgueiro R, Kálmán Török, Gábor Kovács, Csaba Vígh, González J, Marino E, Somoza L, Medialdea T, Blasco I, Kuhn T, Ferreira P, Magalhães V, Malyuk B	2020	Producing a predictivity map outlining the CRM exploration potential areas and the major prospective minerals belts	D3.3, 143 p.	- not public -	FRAME
Sadeghi M, Pereira A, Bertrand G, Arvanitidis N, de Oliveira D, Gautneb H, Gloaguen E, Törmänen T, Reginiussen H, Decree S, Sievers H, Quental L, Bergman T, Hallberg A, McGrath E, Lynch E, Delgado Arenas P, Sánchez SMT, Teran K, Munteanu M, Horváth Z, Török K, Jonsson E, Salgueiro R, Kovács G, Vígh C, González J, Marino E, Somoza L, Medialdea T , Blasco I, Thomas Kuhn T, Ferreira P, Magalhães V, Malyuk B	2020	Providing a data platform, digital version of metallogenic map and related description report highlighting the endowment and exploration potential of CRM in Europe	D3.2, 29 p.	- not public -	FRAME
Sadeghi M, Pereira A, Quental L, Bertrand G, de Oliveira D	2021	Providing CRM data and intelligence to EURMKB (RM1) and the GeoERA information platform	D3.4, 36 p.	- not public -	FRAME
Schiellerup H	2019	Deliverable 2.3 – Workshops dedicated to the main themes of the work packages	D2.3-2, 144 p.	https://geoera.eu/wp-content/uploads/2021/11/MINDeSEA_D2-3-2_WP2-Workshop-Report.pdf	MINDeSEA

continuation table A 4

Author(s)	Year	Title	Deliverable	URL	Project
Schiellerup H	2021	Deliverable 3.2 – Database and maps on hydrothermal mineralisation	D3.2, 4 p.	https://geoera.eu/wp-content/uploads/2021/11/MINDeSEA_D3-2_WP3-Database-and-maps-on-seafloor-hydrothermal-mineralisation.pdf	MINDeSEA
Schiellerup H, Ferreira P, González FJ, Marino E, Somoza L, Medialdea T	2021	Deliverable 3.3. Metallogeny of hydrothermal deposits in European waters	D 3.3, 66 p.	https://geoera.eu/wp-content/uploads/2021/06/MINDeSEA_D3-3_WP3-Metallogeny-of-hydrothermal-deposits-in-European-waters.pdf	MINDeSEA
Schiellerup H, González FJ, Marino E, Ferreira P, Somoza L, Medialdea T	2021	Deliverable 3.3 – Metallogenic Map of Hydrothermal Occurrences in pan-European Seas.	D 3.3, 1 map	https://geoera.eu/wp-content/uploads/2021/11/MINDeSEA_D3-3_WP3-Metallogenic-map-of-hydrothermal-mineralisation.jpg	MINDeSEA
Schiellerup H, González FJ, Marino E, Somoza L, Medialdea T, Ferreira P	2021	Deliverable 3.4 – The metal potential of hydrothermal mineral deposits in European waters	D 3.4; 17 p.	https://geoera.eu/wp-content/uploads/2021/11/MINDeSEA_D3-4_WP3-Hydrothermal-prospectivity.pdf	MINDeSEA
Sievers H	2021	Site specific information in the raw materials data bank	D7.5, 14 p.	- not public -	FRAME
Sievers H, Angelatou V, Bjerkgård B, Hallberg A, Malyuk B, Matos J, Mikulski S, Munteanu M, Pereira Z, Rambusek P, Regeniussen H, Serra M, Teran K	2019	Identification of potential target areas for case studies	D7.1, 71 p.	- not public -	FRAME
Sievers H, Bjerkgård B, Hallberg A, Melnyk I, Mikulski S, Rambousek P, Regeniussen H, Teran K	2020	Historic Mine Sites Revisited – Case Studies	D7.3, 84 p.	- not public -	FRAME
Sievers H, Hallberg A, Munteanu M, Rambousek P, Regeniussen H, Serra M, Teran K	2021	Historic Mine Sites Revisited – Final Report	D 7.4, 78 p.	- not public -	FRAME
Sievers H, Rambousek P	2020	Template for content of case studies to ensure consistent data collection	D7.2, 12 p.	- not public -	FRAME
Simoni M, Aasly KA, Eilu P, Schjøth F	2021	Deliverable 4.1 – Case study review with guidance and examples for applying the UNFC to European mineral resources	D4.1, 24 p.	https://repository.europegeology.eu/egdidocs/mintell4eu/d41-mintel-l4eu-case-study-overview-final.pdf	MINTEL-L4EU

continuation table A 4

Author(s)	Year	Title	Deliverable	URL	Project
Somoza L, Zalba I, González FJ, Marino E, Medialdea T, Lobato A, Blasco I, Nyberg J	2021	Deliverable 7.3 – Exploration Cruises carried out and Mineral Potential and Prospectivity Areas in pan-European	D 7.3, 1 map	https://geoera.eu/wp-content/uploads/2021/11/MINDeSEA_D7-3_WP7-Exploration-cruised-carried-out-and-mineral-potential-and-prospectivity-areas-in-pan-European-Seas-scaled.jpg	MINDeSEA
Somoza L, Zalba I, González FJ, Marino E, Medialdea T, Lobato A, Blasco I, Nyberg J	2021	Deliverable 7.3 – Exploration Cruises carried out and Mineral Potential and Prospectivity Areas in pan-European. Zone A	D 7.3, 1 map	https://geoera.eu/wp-content/uploads/2021/11/MINDeSEA_D7-3_WP7-zone_A-scaled.jpg	MINDeSEA
Somoza L, Zalba I, González FJ, Marino E, Medialdea T, Lobato A, Blasco I, Nyberg J	2021	Deliverable 7.3 – Exploration Cruises carried out and Mineral Potential and Prospectivity Areas in pan-European. Zone B	D 7.3, 1 map	https://geoera.eu/wp-content/uploads/2021/11/MINDeSEA_D7-3_WP7-zone_B-scaled.jpg	MINDeSEA
Somoza L, Zalba I, González FJ, Marino E, Medialdea T, Lobato A, Blasco I, Nyberg J	2021	Deliverable 7.3 – Exploration Cruises carried out and Mineral Potential and Prospectivity Areas in pan-European. Zone C	D 7.3, 1 map	https://geoera.eu/wp-content/uploads/2021/11/MINDeSEA_D7-3_WP7-zone_C-scaled.jpg	MINDeSEA
Somoza L, Zalba I, González FJ, Marino E, Medialdea T, Lobato A, Blasco I, Nyberg J, the MINDeSEA Team	2021	Deliverable 7.4: Literature review report on present-day status of exploration for submarine mineral deposits around Europe	E.7.4, 30 p.	https://geoera.eu/wp-content/uploads/2021/11/MINDeSEA_D7-4_WP7-%E2%80%93-Present-day-status-of-exploration-for-seabed-minerals.pdf	MINDeSEA
Somoza L; the MINDeSEA Team	2021	Deliverable 7.2 – Database and maps on exploration in pan-European seas	D 7.2, 7 p.	https://geoera.eu/wp-content/uploads/2021/11/MINDeSEA_D7-2_WP7-Database-and-maps-on-exploration-in-pan-European-seas.pdf	MINDeSEA
WP8 -FRAME	2020	Implement IT equipment infrastructure capable of interacting with internal system requirements to ensure delivery and increase the reliability of data and information to the EURMKB	D8.2, 9 p.	- not public -	FRAME
Zananiri I	2021	Deliverable 5.4: Report of the models of formation for the main provinces of placer occurrence, as defined through this study	D 5.4, 50 p.	https://geoera.eu/wp-content/uploads/2021/11/MINDeSEA_D5-4_WP5-PlacerDeposits_Models-of-formation.pdf	MINDeSEA

continuation table A 4

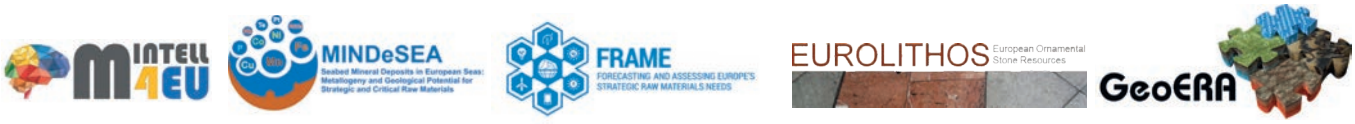
Author(s)	Year	Title	Deliverable	URL	Project
Zananiri I	2021	Deliverable 5.5 – WP5 Literature review report on present-day status of regulation, legislation and exploitation of placer deposits, with emphasis on the impact of a pan-European research approach	D 5.5, 32 p.	https://geoera.eu/wp-content/uploads/2021/11/MINDeSEA_D5-5_WP5-PlacerDeposits_PresentDayStatus.pdf	MINDeSEA
Zananiri I, Zimianitis V, Georgakopoulos N, González FJ, Marino E, Somoza L, Medialdea T	2021	Deliverable 5.2 – Database and maps on marine placers	D 5.2, 4 p.	https://geoera.eu/wp-content/uploads/2021/11/MINDeSEA_D5-2_WP5-Database-and-maps-on-marine-placers.pdf	MINDeSEA
Zananiri I, Zimianitis V, Georgakopoulos N, González FJ, Marino E, Somoza L, Medialdea T	2021	Deliverable 5.3 - Potential and Prospectivity Map of Placers Occurrences in pan-European Seas	D.5.3, 1 map	https://geoera.eu/wp-content/uploads/2021/11/MINDeSEA_D5-3_WP5-Mineral-potential-and-prospectivity-map-of-placers.jpg	MINDeSEA

Table A 5: *Author Contribution in an EU Open Publication compliant format.*

Task	Role Definition	Name of Contributer (alphabetic order)
Conceptualization	*Ideas; formulation or evolution of overarching research goals and aims.*	*Lisbeth Flindt Jørgensen, Francisco Javier González Sanz, Tom Heldal, Daniel de Oliveira, Gerry Stanley, Antje Wittenberg*
Data Curation	*Management activities to annotate (produce metadata), scrub data and maintain research data (including software code, where it is necessary for interpreting the data itself) for initial use and later reuse.*	*Trevor Alcorn, Blaž Bahar, Jorge M. F. Carvalho, Željko Dedić, Lisbeth Flindt Jørgensen, Francisco Javier González Sanz, Tom Heldal, Tjerk Heijboer, Špela Kumelj, Konstantinos Laskaridis, Ana Lobato, Egidio Marino, Daniel de Oliveira, Christian Brogaard Pedersen, Aurete Pereira, Lídia Quental, Frands Schjøth, Jørgen Tulstrup, Andrej Vihtelič, David Whitehead,*
Formal Analysis	*Application of statistical, mathematical, computational, or other formal techniques to analyze or synthesize study data.*	*Trevor Alcorn, Pedro Ferreira, Ana Lobato, Egidio Marino, Xavier Monteys*
Funding Acquisition	*Acquisition of the financial support for the project leading to this publication.*	*Paul J.F. Bogaard, Mart van Bracht, Tirsa M. van Daalen, Luca Demiceli, Johnny Frederica, Hans-Joachim Kümpel, Koen Verbruggen, Patrick Wall, Antje Wittenberg*
Investigation	*Conducting a research and investigation process, specifically performing the experiments, or data/evidence collection.*	*Guillaume Bertrand, Iker Blasco, Teresa Calabaça, Georgy Cherkashov, Sophie Sophie Decrée, Maria João Ferreira, Pedro Ferreira, Eric Glouagen, Håvard Gautneb, James R. Hein, Francisco Javier González Sanz, Thomas Kuhn, Vitor Magalhaes, Boris Malyuk, Egidio Marino, Teresa Medialdea, Johan Nyberg, Daniel de Oliveira, Aurete Pereira, Lídia Quental, Isabel Real, Helge Reginuissen, Martiya Sadeghi, Henrik Schiellerup, Henrike Sievers, Luis Somoza, Tuomo Tormanen, Íñigo Zalba, Irene Zananiri*
Methodology	*Development or design of methodology; creation of models.*	*Trevor Alcorn, James Trench*
Project Administration	*Management and coordination responsibility for the research activity planning and execution.*	*Lisbeth Flindt Jørgensen, Francisco Javier González Sanz, Tom Heldal, Daniel de Oliveira, Antje Wittenberg*
Resources	*Provision of study materials, reagents, materials, patients, laboratory samples, animals, instrumentation, computing resources, or other analysis tools.*	*GeoERA Raw Materials Consortium*
Software	*Programming, software development; designing computer programs; implementation of the computer code and supporting algorithms; testing of existing code components.*	*Trevor Arlon, Blaž Bahar, Tjerk Heijboer, Špela Kumelj, James Passmore, Aurete Pereira, Bjarni Pjetursson, Lídia Quental, Frands Schjøth, James Trench, Andrej Vihtelič*
Supervision	*Oversight and leadership responsibility for the research activity planning and execution, including mentorship external to the core team.*	*Lisbeth Flindt Jørgensen, Francisco Javier González Sanz, Joop Hasselman, Tom Heldal, Daniel de Oliveira, Yvonne A. Schavemarker, Tessa T. Witteman, Antje Wittenberg*
Validation	*Verification, whether as a part of the activity or separate, of the overall replication/ reproducibility of results/experiments and other research outputs.*	*Gerry Stanley*
Visualization	*Preparation, creation and/or presentation of the published work, specifically visualization/data presentation.*	*Jolante Duba, Antje Wittenberg*

continuation table A 5

Task	Role Definition	Name of Contributer (alphabetic order)
Writing – Original Draft Preparation	*Creation and/or presentation of the published work, specifically writing the initial draft (including substantive translation).*	*Kari Aslaksen Aasly, Eimear Deady, Lisbeth Flindt Jorgensen, Francisco Javier González Sanz, Tom Heldal, Zoltan Horvath, Eoin McGrath, Daniel de Oliveira, Henrike Sievers, Antje Wittenberg*
Writing – Review & Editing	*Preparation, creation and/or presentation of the published work by those from the original research group, specifically critical review, commentary or revision – including pre- or post-publication stages.*	*Lisbeth Flindt Jørgensen, Francisco Javier González Sanz, Tom Heldal, Daniel de Oliveira, Gerry Stanley, Antje Wittenberg*


MINTELL 4EU
MINDeSEA
Seabed Mineral Deposits in European Seas: Metallogeny and Geological Potential for Strategic and Critical Raw Materials
FRAME
FORECASTING AND ASSESSING EUROPE'S STRATEGIC RAW MATERIALS NEEDS
EUROLITHOS
European Ornamental Stone Resources
GeoERA