The Geological Survey Organisations in delivering Critical Raw Materials autonomy through a Geological Service for Europe

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A b s t r a c t. Europe's dependence on foreign-sourced critical raw materials poses a significant threat to its strategic autonomy and competitiveness. In this paper, we examine the historical significance of mining in Europe, the current geopolitical complexities surrounding critical raw materials supply, and recent EU policy initiatives aimed at bolstering domestic critical raw materials production and processing and building resilient supply chains. We highlight the crucial role of National Geological Survey Organisations in delivering knowledge of Europe's critical raw materials potential, as well as contributing to international partnerships through technical engagement and geoscientific diplomacy. National Geological Survey Organisations collect and compile data on mineral resources, often serving as a primary resource for national and regional decision-making. This work is now crucial at EU level, with National Geological Survey Organisations mandated under the EU Critical Raw Materials Act to deliver National Exploration Programs to promote exploration investment through technical de-risking, and to coordinate efforts and geoscientific data and knowledge management at pan-European level. The National Geological Survey Organisations already share knowledge and best practices on European mineral resources through EuroGeoSurveys. Future efforts to secure European critical raw materials resilience will be served through their shared vision of a Geological Service for Europe.

Keywords: *Critical Raw Materials Act, National Exploration Programmes, European Geological Data Infrastructure, UNFC*

INTRODUCTION

Despite Europe's rich mining history spanning thousands of years and its significant impact on societal, economic, and technological development, the strength of the mining sector has declined. In the latter half of the 20th century, despite discoveries like that of the Kupferschiefer Cu-Ag deposit in Poland, raw material sourcing largely shifted abroad, a trend that persists today. European mine production fell over 35% in the past 20 years, unlike other continents, which have seen increases (Reichl and Schatz, 2024). Exploration budgets in Europe dropped 3% year-over-year, following a 15% decline in 2022 due the Russian invasion of Ukraine and related sanctions (S&P Global, 2024). Currently, <3% of Europe's raw materials are domestically sourced, leaving it vulnerable to external dependencies in an unstable geopolitical climate. This threatens Europe's strategic autonomy amidst global competition for critical raw materials (CRMs), essential for the green and digital transition central to EU strategy.

CRMs, with high economic importance and supply risks, are vital to industries such as technology, energy, and manufacturing, including such applications as batteries, turbines, and solar panels. Strategic raw materials (SRMs), a CRM subset, support key technologies and defense. In 2023, the EU identified 34 CRMs, 17 of which are SRMs, including cobalt, rare earth elements, lithium, and nickel. These materials underpin Europe's economy and industrial base, ensuring strategic autonomy and competitiveness.

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To address CRM dependencies, the EU's Critical Raw Materials Act (2023) focuses on boosting domestic supply chains via increased production, recycling, and sustainable sourcing. This paper highlights the role of National Geological Survey Organisations (NGSOs) in enhancing Europe's competitiveness by fostering CRM autonomy. NGSOs, mandated to deliver geological knowledge, are tasked with supporting National Exploration Programs (NEPs) to attract investment by reducing technical risks. NGSO also leverage EuroGeoSurveys' 50 years of collaboration, expertise, and best practices. This collaboration underpins the vision for a Geological Service for Europe to deliver cross-border cooperation, elevate CRM expertise, and advance the CRMs Act. These efforts are critical to rebuilding Europe's raw materials sector, ensuring supply chain security, and strengthening its autonomy and competitiveness.

CRITICAL RAW MATERIALS IN EUROPE

European exploration and mining history

Mining and metallurgy have been fundamental drivers of human progress in Europe, profoundly shaping technological advancement, social organization, and economic systems across millennia. The story of European mining reveals how the control and processing of mineral resources catalysed major civilizational transitions and fostered the development of complex societies.

The Chalcolithic Age (or Copper Age, ~4500–2200 BC) marked humanity's first systematic ventures into mining, with copper the first metal to be extensively exploited. In southeastern Europe, archaeological evidence reveals sophisticated copper mining operations as early as 5000 BC, e.g., the Rudna Glava mine (modern-day Serbia) and the Ai Bunar mine (Bulgaria) (Jovanović, 1978, 1980). These initial mining operations required considerable organizational capacity. The ability to extract and process copper ores led to the emergence of specialized craftsmen and traders, contributing to social stratification and development of early hierarchical societies.

The Bronze Age (~2200–800 BC) witnessed a revolutionary transformation in mining and metallurgy. The discovery that combining copper with tin created a superior metal – bronze – sparked an unprecedented demand for mineral resources. This period saw the establishment of extensive trade networks across Europe to source tin (Muhly, 1973). The tin mines of Cornwall in Britain and the copper mines of the eastern Alps became crucial centres of production. Mining operations grew more sophisticated, with deeper shafts and more complex underground galleries. This period also saw the emergence of mining communities and specialized metalworking centres, leading to the development of new social structures and trading systems. The organization required for bronze production contributed to the rise of elite classes and centralized authorities. Mining settlements became important centres of wealth and power, such as Mitterberg in Austria (Pernicka *et al.*, 2016) and Great Orme in Wales (Williams and Le Carlier de Veslud, 2019). The control of mineral resources and trade routes became a source of political power, influencing the formation of early European chiefdoms and kingdoms.

The Roman Empire (27 BC–476 AD) brought unprecedented scale and sophistication to mining operations across Europe. The Romans developed extensive mining operations in Spain (Rio Tinto; Jones, 1980), Britain (Dolaucothi gold mines; Burnham, 1997), Portugal (e.g., Três Minas Mining Compound; Noronha, Ramos, 1993), and Romania (Roșia Montană and Bucium gold mines; Ciugudean, 2012). They introduced advanced engineering techniques including hydraulic mining, which used pressurized water to break down ore-bearing rock faces. The Romans also established sophisticated administrative systems for managing mines, with many operations directly controlled by the imperial government. Their legal framework for mining operations influenced medieval mining laws.

The Middle Ages (5^{th}–15^{th} centuries) brought significant advances in mining technologies and organization, seeing the emergence of more systematic mining operations, particularly in central Europe. The silver mines of Kutná Hora in Bohemia (Hruby, 2024), the copper mines of the Harz Mountains (Asmus, 2012), and the salt mines of Wieliczka in Poland (Hallett, 2003) became crucial to the medieval European economy. Mining rights and regulations were formalized, with rulers granting mining privileges and establishing mining towns with special legal status (e.g., Kutná Hora in modern Czech Republic, Freiberg and Goslar in Saxony, and Banská Štiavnica in Slovakia). Technical innovations transformed mining operations. The introduction of water-powered machinery for pumping and ore processing, improved ventilation systems, and new smelting techniques allowed for deeper and more extensive mining operations.

The Early Modern Period (16^{th}–18^{th} centuries) witnessed further metallurgical innovations driven by expanding global trade and emerging scientific approaches. German and Czech mining regions became global leaders in metallurgical knowledge. Breakthrough publications like Georgius Agricola's "De Re Metallica" (1556) systematised mining and metallurgical knowledge, introducing scientific principles to what had previously been largely craft-based practices. Improved smelting techniques, better understanding of mineral chemistry, and more efficient extraction methods gradually transformed mining from a local economic activity to a sophisticated, knowledge-driven industry.

The Industrial Revolution (late 18^{th}–19^{th} centuries) marked a watershed in European mining history. The demand for coal to power steam engines led to unprecedented expansion of mining operations. The coal fields of Britain, Germany's Ruhr Valley, and other regions became the powerhouses of industrial growth. Iron ore mining expanded dramatically to meet the needs of a growing industrial production. New technologies, such as steam-powered pumps and improved explosives, allowed new developments in mining engineering and large-scale industrial mining operations, employing thousands of workers. Mining became increasingly mechanized and scientifically managed. The concentration of workers in mining regions led to the development of new urban centres, such as Essen and Dortmund in the Ruhr region, Merthyr Tydfil and Cardiff in Wales, Birmingham in England, Lens and Valenciennes in France, and Katowice in Upper Silesia.

Throughout these periods, mining played crucial roles in technological advancement. The challenges of extracting and processing minerals drove innovation in tools, techniques, and organizational systems. Mining activities required and fostered developments in geology, engineering, and chemistry. The wealth generated from mining funded

Fig. 1. Historical engraving of the Wieliczka salt mine, Poland, 1809

scientific research and technological development, creating a positive feedback loop of innovation and progress.

The environmental impact of mining also shaped European landscapes and societies. Historic mining regions bear the marks of centuries of extraction, from ancient slag heaps to industrial era mine wastes. These environmental challenges spurred early attempts at resource management and environmental protection, influencing modern approaches to sustainable resource use.

The history of European mining reflects the broader story of human civilization: the transition from simple stone tools to complex industrial societies. Each major advance in mining technology and organization corresponded with significant social, economic, and political changes. The control of mineral resources influenced the rise and fall of powers, the development of trade networks, and the emergence of new social structures. This legacy continues to influence modern Europe, with many former mining regions transforming into centres of technological innovation and cultural heritage.

Current Critical Raw Materials Geopolitics

Current geopolitical instability is significantly affecting the supply of CRMs, with competition for these resources intensifying on a global scale. The increasingly complex geopolitical landscape concerning CRMs in Europe is shaped by this global competition, as well as environmental concerns, and the transition to green technologies. The competition for CRMs is not just limited to Europe (and other developed economies): it also involves emerging economies. African countries, such as the Democratic Republic of the Congo (DRC), are rich in cobalt, a key component in lithium-ion batteries. As global demand for electric vehicles increases (IEA, 2024), the DRC has become a focal point for investment. However, this has raised ethical concerns regarding labour practices and environmental sustainability (e.g., Haider, 2023).

As Europe aims to reduce its reliance on fossil fuels and enhance its technological capabilities, the demand for CRMs – such as lithium, cobalt, and rare earth elements – has recently surged. For its access to CRMs, the EU depends heavily on international markets. While some domestic production and processing capacity exists (e.g., cobalt in Finland; Konnunaho *et al*., 2023), most CRM value chains in Europe only begin at the refining or manufacturing stages. EU reliance on imports varies greatly, not only by raw material, but also by its stage of processing. As of March 2020, the EU was over 95% import-reliant for 15, and over 60% import-reliant for an additional 7, of the 27 materials or material groups designated as CRMs. China is by far the EU's most important supplier, accounting for 62% of its total CRM imports, while other key suppliers include the United States, Russia, Brazil, and Nigeria (Theodosopoulos, 2020). China's virtual strangle-hold on CRM supply and its threats to European strategic autonomy and competitiveness were dramatically exposed in recent years when China tightened controls on supplies of gallium and germanium (Harper, 2023; Liang and Marsh, 2023), which are crucial components of microchips, magnesium (Imahashi, 2021), which is used in aluminium alloys in the auto industry and in steel production, and antimony (Dareen, 2024), which is used in flame retardants, alloys and batteries. This has led to increased geopolitical tensions.

The minerals-rich Ukraine (e.g., Mykhailov *et al*., 2023) is now a focal point of severe geopolitical instability. The invasion of Ukraine by Russia in 2022, and the subsequent EU sanctions against Russia, led rapidly to an energy crisis across Europe. Tensions have only increased with strong EU support for both Ukraine's defence effort against Russia and its accelerated path toward NATO membership. The war has disrupted supply chains and prompted European nations to seek alternative sources of energy and raw materials, emphasizing the need for diversification.

In efforts to strengthen ties with 'friendly' partners, the EU joined the US-initiated Minerals Security Partnership in 2022, a partnership currently with 15 members, namely Australia, Canada, Estonia, Finland, France, Germany, India, Italy, Japan, Norway, South Korea, Sweden, the United Kingdom, the United States, and the European Union. A similar initiative was launched by the EU itself in 2024, with the CRM Club, with the aim of providing a forum for like-minded countries willing to strengthen global supply chains.

The current geopolitical landscape in Europe regarding CRMs is characterized by increasing awareness of supply vulnerabilities, a focus on strategic partnerships aimed at securing supplies, a commitment to sustainability, and an ongoing effort to reduce dependence on external sources, particularly amid heightened global tensions.

European policy developments to support strategic autonomy and competitiveness

Recognising its strong CRM import dependencies already in 2008 (but still almost two decades after China identified and began investing heavily in the rare earth element market in particular) the EU established the European Raw Materials Alliance, with the aim of creating a more sustainable and circular economy by promoting the extraction and recycling of raw materials within Europe. This effort was further bolstered after 2017 with introduction of the European Green Deal (European Commission, 2019), its commitment to achieving carbon neutrality by 2050 underscoring the necessity of securing a stable supply of CRMs.

Nonetheless, the continuing weakness of European CRM supply security, and its implications for broader strategic autonomy, came into sharp focus first during the Covid-19 pandemic in 2020 – which highlighted the impact of supply chain disruption to the European industry and economy – followed shortly thereafter by the Russian war on Ukraine in 2022 – which dramatically exposed Europe's foreign energy dependence. These, and intermittent Chinese CRM supply disruptions (Imahashi, 2021; Harper, 2023; Liang and Marsh, 2023), have clarified the urgent need for new policy to support Europe's strategic autonomy and competitiveness.

In May 2024, the EU CRM Act entered into force after a rapid path through the EU legislative process of only 14 months. The CRM Act is a regulation – directly enforceable in the 27 Member States – which targets building EU resilience of access to CRMs and SRMs. The specific aims of the CRM Act include increasing domestic (European) production and processing of CRMs, increasing circularity through re-mining of mine waste and recycling, anticipation and mitigation of supply risks, establishing or strengthening strategic partnerships with like-minded third countries to support CRM supply chains, and promoting sustainable sourcing practices (e.g., Hool *et al*., 2024). Specifically, the CRM Act sets benchmarks for 2030, including:

- The EU's extraction capacity covers at least 10% of the EU's SRM consumption;
- The EU's processing capacity covers at least 40% of the EU's SRM consumption;
- The EU's recycling capacity covers at least 25% of the EU's SRM consumption;
- Not more than 65% of the EU's consumption of each SRM is sourced from a single third country.

During the legislative process leading up to and following implementation of the CRM Act, the EU accelerated its efforts to establish bilateral international strategic partnerships on raw materials. These partnerships have common overarching aims including integration of sustainable raw materials value chains, cooperation on research and innovation, application of high environmental, social, and governance standards, mobilisation of funding and investment, and capacity building and skills development. The bilateral partnerships, secured through non-binding MoUs, are supported by strategic roadmaps that identify key contributing organisations who can provide technical and financial support. The first strategic partnerships were established with Canada and then Ukraine in 2021, followed in 2022 by Kazakhstan and Namibia. In 2023, the EU signed with Argentina, Chile, DRC, Zambia, and Greenland, and in 2024 with Rwanda, Norway, Uzbekistan, Australia, and Serbia, with more likely to follow.

In parallel to the CRM Act, the EU Net Zero Industry (NZI) Act also moved quickly through the legislative process and entered into force in June 2024. The NZI Act – also a regulation – specifically targets technologies crucial for decarbonisation, particularly through the development of a new carbon storage industry. Together, the NZI Act and the CRM Act create a regulatory framework to boost the competitiveness of EU industry and technologies crucial for decarbonisation and to address pressing challenges faced by the EU in the strategic sectors of decarbonization, digitalization, and aerospace and defence.

THE ROLE OF THE EUROPEAN NATIONAL GEOLOGICAL SURVEY ORGANISATIONS IN EUROPE'S CRITICAL RAW MATERIALS AUTONOMY

European National Geological Survey Organisations in delivering knowledge of Critical Raw Materials

NGSOs are typically national public research or administrative institutes or agencies with a mandate to deliver knowledge of the geology of their territories to inform policy and to provide public information. This mandate includes (and is often focussed on) data, knowledge, and advice regarding mineral resources. To implement national strategies on resource management and support the decision-making process, governments and industries need to understand the supply and demand dynamics of raw materials. Information such as raw material occurrences, current and past mining activities, and knowledge of resources and reserves is a prerequisite. NGSOs play a central role in collecting and compiling data on raw materials and, in many cases, also in monitoring mining activities. Most NGSOs host data on raw materials within their territories, often available as interactive digital maps, yearly reports and/or long-term time-series compilations. This data is primarily designed to serve national and regional requirements, including derisking exploration investment through provision of pre-competitive technical geological data.

European National Geological Survey Organisations in the Critical Raw Materials Act

While the importance of NGSO work to understand the mineral resource endowment and potential of national territories has long been recognized, the CRM Act further

highlights the relevance of this work of the NGSOs not just at national level, but also in contributing to Europe's CRM autonomy at continental scale. The CRM Act specifically refers to the role(s) of the NGSOs in its Articles 35 and 36, which refer to the composition and functioning of a European CRM Board. This Board, composited of Member States and the Commission, will establish a minimum set of subgroups, which includes a subgroup bringing together "national geological institutes or surveys…with the purpose of contributing to the coordination of national exploration programmes referred to in Article 19." The Article 19 referred to elaborates on the National Exploration Programmes (NEPs), required to be drawn up at national level and addressing "general exploration targeted at critical raw materials." The specific activities referred to that could or should form the scope of the NEPs lie wholly within the common mandates of the NGSOs, thus explaining direct reference to these organisations in the regulation. Article 19 identifies as within the scope of the NEPs:

- Mineral mapping;
- Geochemical campaigns;
- Geoscientific surveys such as geophysical surveys;
- Processing of data, including predictive maps;
- Reprocessing of existing geoscientific survey data.

These data are required to be made publicly available, using the United Nations Framework Classification for Resources (UNFC) code (UNECE, 2020) where applicable.

Additional areas where the NGSOs are likely to play important roles, given that they also fall within the scope of NGSO common activities and mandates, include mapping of historical mine waste sites, and characterisation and reporting of the CRM potential of mining waste. Indeed, these are also activities addressed in current pan-European collaborative projects in which many NGSOs participate, e.g., FutuRaM, and SCRREEN. The CRM Act is the first piece of EU legislation that delivers an EU legal mandate to the European NGSOs.

National Geological Survey Organisations in delivering the National Exploration Programmes: status and future plans

The main objective of the National Exploration Programmes (NEPs) is to provide up-to-date data on mineral potential, identify new exploration targets, and attract investment and exploration companies to carry out detailed exploration for CRMs and other commodities on the territory of the EU Member States. Since the 1980s, the EU has experienced a decline in mining sector activities and metal ore processing (Wagner, Fettweis, 2001), which has also had a strong impact on overall geological data collection and mineral exploration activities. While some countries with larger ore deposits and favourable geological conditions (e.g., Sweden, Finland, Poland, Ireland, Spain, Portugal, Greece) have maintained mining and exploration activities, other countries have a significant gap of 40 or more years without continuous data collection and exploration for metal mineral resources. As a result of technological progress, the expansion of the range of raw materials required and exploited, and more precise chemical analyses, the existing data in these areas is outdated and insufficient to predict CRM potential. The provision of continuously conducted and funded NEPs is a prerequisite to fill gaps where they exist and to create a solid basis for the continuation of exploration programmes in countries that already carry out these activities.

Following the entry into force of the CRM Act, most EU Member States have recognized the knowledge and experience of their NGSOs and given them the mandate to develop NEPs. In some cases, the NEP is prepared in cooperation between the NGSO and state-owned companies (e.g., in the Czech Republic) or semi-private companies and representatives of specialized ministerial departments (e.g., in Portugal), depending on the mandates of each organisation.

The drafts of the NEP differ depending on the geological conditions of the country, the exploration activities carried out in last decades, and the planned budget. The NEPs focus on at least some of the activities listed:

- Desktop study: collection of existing literature and data, reassessment, reinterpretation, and digitisation where necessary for baseline definition;
- Regional airborne multisensory geophysics (magnetic/radiometric, gravity, electromagnetic domain);
- Geochemical sampling of stream sediments and soils on a regional scale;
- Lithogeochemistry of mineralised lithological units.
- Geological and structural mapping combined with petrological and geochronological research and evaluation;
- Ground geophysics;
- Exploration drilling;
- Preparation of prospectivity and metallogenic maps;
- Mapping and sampling of mining wastes;
- Activities to strengthen social acceptance of mining;
- Development of mineral observatories and updating of national mining strategies.

All NGSOs in the EU Member States agree that all the activities listed above are for pre-competitive exploration aimed at better understanding the geological setting and identifying prospective areas that would be attractive for private companies to secure exploration concessions and begin targeted detailed exploration activities. In some countries, however, the NGSOs are not directly involved in the preparation of the respective NEP, or they have no information on the status of its preparation (e.g., Croatia). In such cases, the NGSO has begun desktop studies and literature reviews internally to assess the most promising areas with CRM occurrences to be prepared for potential activities if they are allocated to them. The development and scope of the NEPs in the EU Member States is closely linked to the status of their mining sector. Countries with active metal mining and mineral processing industries are quicker and more agile in preparing NEPs, as they are aware of the importance of such programmes for their economies. At the time of writing, an NEP has only been officially introduced in France and Greece, with the Czech Republic being close to introduce one.

The **Greek** geological survey began implementing an NEP on 1 September 2024 and is mainly focused on the re-evaluation and exploration of copper, antimony, lithium, and rare earth element potential. They will also sample mining waste and technologically investigate the potential production of special materials with high added value. The duration of the NEP is 3 years.

In **France**, the French geological survey has prepared an NEP for a period of 5 years. It has been implemented since 1 September 2024 and is also a consequence of the government's decision to launch a new inventory of mineral re-

sources which was accepted in September 2023. Exploration activities include geophysical surveys, geochemical sampling, and the evaluation of data at regional level. The main targets are areas with outcrops of basement rocks in the northern Massif Central, the eastern Pyrenees and Cévennes, the Vosges mountains, and areas in northern French Guyana. In recent years they have carried out pilot studies in smaller areas to test the combination of different exploration approaches and techniques.

In **Poland**, the draft NEP includes identification of the possibility of the presence of all 34 CRMs in Poland. Planned exploration work will include, in addition to verification of archival materials, geophysical surveys, chemical analyses of archived borehole core (chemical analyses of only a few elements were performed previously), geochemical mapping (primarily in the Polish part of the Bohemian Massif), and exploratory drilling. This reconnaissance stage is expected to last 5 years. The Polish Geological Institute – National Research Institute (PGI-NRI) also publishes the Balance of Prospective Resources of Poland every 10 years, containing a compendium of the status of the country's resource reconnaissance (last edition: Szamałek *et al*., 2020)

The NEP of the **Czech Republic** will not only focus on re-evaluation of existing data and geophysical and geochemical surveys, but also involves planned drilling of some exploration boreholes in areas that show the greatest potential for CRMs. This pre-competitive drilling programme is necessary to secure access to the land for mining, as deposits without estimated resources cannot be reserved for mining due to national legislation.

Other EU countries are in the process of preparing their NEPs. It is not expected that their content and scope will be published any earlier than the official deadline of May 2025. However, the European CRM Board's subgroup for NEPs and the EGS Mineral Resource Expert Group (MREG) are constantly exchanging information on the progress of NEP preparation. In addition, EGS has now established a specific MREG subgroup on the National Exploration Programmes to support knowledge-sharing and common approaches to this issue of strategic European importance.

Austria, Cyprus, Estonia, Finland, Ireland, and **Sweden** have not yet formally adopted their NEPs, but their activities have actually pre-empted the entry into force of the CRM Act. They are either continuously carrying out exploration activities on their territory or have launched a targeted national initiative/exploration programme in recent years, including for CRMs, to respond to market and economic challenges. With the adoption of the NEPs, it is expected that these activities will be further expanded.

The **Swedish** Geological Survey has conducted several projects over the past seven years that have focused on sampling its mining waste to assess its potential for reprocessing. Although the NEP has not been officially adopted in Sweden, the Swedish Geological Survey has received additional funding for the period 2024–2026 to explore areas considered promising for new ore bodies that also contain CRMs.

The **Irish** Geological Survey has been carrying out a national programme to collect geochemical and geophysical data across Ireland named (named the Tellus survey) for 20 years (GSI, 2021). The data is used for a variety of purposes, with mineral resources and CRM just one of them.

The **Austrian** Geological Survey has received funding for decades for the implementation of the CRM Act. As part of this activity, they cover the investigation of national raw material potential, such as mapping, geochemical sampling, and the maintenance of data portals. With the implementation of the NEP, they plan to double the funds and carry out targeted exploration activities in the most promising areas with CRM potential.

The NGSOs in other countries are engaged in exploration or scientific research on topics related to mineral resources – the **Cyprus** Geological Survey is investigating the potential of mining waste from their VMS deposits, while the **Estonian** Geological Survey is assessing the potential of phosphorite and other deposits.

However, some countries where there are no known CRM deposits in the shallow or near-surface sediments and sedimentary rocks (e.g., **Denmark**) will develop their NEP to demonstrate that there is no CRM potential in their territory, also allowed under the CRM Act. This does not mean that there are no CRM deposits in the basement rocks at great depths, but in the current situation their exploration and development is not economically feasible.

For many years, the NGSOs have alerted policymakers and the public to the fact that a reassessment and cross-border harmonization of existing data is not enough to make significant advances in increasing the domestic supply of raw materials, especially CRMs (Wittenberg *et al*., 2024). Only new exploration activities, new sampling campaigns, and new geophysical surveys can reveal areas with potential for the discovery of new deposits. The NEPs are a step in the right direction, a step towards long-term and continuous pre-competitive exploration programmes. Constant exploration is the only way to enable the discovery of new ore deposits, which can then attract investors and ultimately result in mining operations. In addition, such exploration ensures continuous development of understanding of geology and related sciences and increases the competences of the NGSOs and their employees.

Availability of experts may be the biggest limitation in the implementation of NEPs, as there are widespread concerns of limited professional capacity for the NEP implementation (e.g., Hollis *et al*., 2024). It is crucial to enable the transfer of knowledge and expertise within the EU, as it is already clear that there is a lack of specialised expertise in some areas, but this will improve after some years of NEP activities.

The NEPs will not only influence the mineral raw materials sector but will also have significant multiplier effects on other sectors such as the assessment of geothermal potential, CO_2 storage potential, assessment of seismic and landslide hazards, locating drinking water sources, environmental studies, and 3D spatial planning, to name but a few. Thus, in addition to strengthening our sovereignty in the supply of mineral resources, NEPs have the potential to save lives and reduce our carbon footprints.

National Geological Survey Organisations in supporting deployment of the United Nations Framework Classification

Information on quantities and grades of mineral resources and reserves is continuously evolving based on improvements in the field of resources management, increased exploration, stage in the mining lifecycle, data availability and

sharing, innovation in exploration and strategic interest in commodities. Company reporting to the stock exchange of mineral resources and reserves must adhere to stringent international codes (e.g., JORC – Australasia, PERC – EU, NI43-101 – Canada, SAMREC – South Africa, etc.). These codes only include estimates at the highest levels of confidence and are based on high-quality and detailed physical evidence obtained by drilling, rock analysis, and 3D-statistical assessments. This requires substantial financial investment (often in tens of millions of euros per mineral deposit), which is associated with high risk.

For mineral resource project development, there are different levels of confidence needed for different stakeholders. Investors and financial institutes need the highest level of confidence in the data, whereas the data on resources for longer term planning and policy decisions – as required for instance by national governments – can be, and are, reported with lower confidence levels.

The data on mineral resources available to NGSOs is generally of a much lower confidence level when compared to the industry data used to prepare code-compliant resource estimation. This data available to NGSOs includes historical estimates, geological information, and indirect evidence, such as geophysical data. Hence, providing reliable, harmonised, fact-based answers to questions by stakeholders and decision-makers such as: "How much is there?", "Where is it?" and "What are the likely chances of actually extracting it?" is a challenging task. In addition to, and as a result of, the different stakeholder needs for the data, a variety of different, non-comparable standards and definitions are used by national bodies and the industry across the EU.

Efforts to compile resource information at an international level have encountered various difficulties and struggle with multiple sources of potential errors or ambiguities. Foremost, the lack of a common standard to communicate resource information of variable uncertainties has been identified as the main area that needs improvement. In this regard, the United Nations Framework Classification for Resources (UNFC) code (UNECE, 2020) is the way forward, because it allows for an international standard, suitable for a range of stakeholders for clear communication of geological uncertainty levels. In addition, it includes two more dimensions: project feasibility and environmental-socio-economic viability. These issues are paramount to the potential for eventually making a resource available to industry and society. The richest mineral deposit has little practical significance if it is located within a protected area, or the access to a mineral deposit is partially or fully limited due to other factors (e.g., groundwater protection, Natura2000, cultural heritage, infrastructure). Adding this information allows a more comprehensive picture.

In applying the UNFC to national mineral resources and occurrences, both deposit- and commodity-specific information must be considered and interpreted. Importantly, there must be a common agreed understanding among the practitioners on the best practice to be followed. In this context, it must be stressed that exploration is continuously improving geological knowledge regarding raw material occurrences in Europe, in particular when deposits cannot be seen at the surface. Scientific research aimed at defining areas of elevated potential of endowment for certain commodities is the focus of many NGSOs. Hence, there is a constant stream of information that needs to be translated into harmonized UNFC-based resource information (Dobnikar *et al.*, 2023). NGSOs will be the organisations to deliver and report on NEPs according to the CRM Act. Paragraph 6 of Article 19 of the CRM Act indicates that the Member States shall make maps that show basic information on mineral occurrences containing CRMs, gathered through the measures set out in the NEPs and that information shall, where applicable, include the classification of the occurrences using the UNFC.

The UNFC is a universal system for classifying and reporting minerals, energy, and other resources. It provides a standardized approach to ensure consistency, transparency, and sustainability in resource management. By integrating environmental, social, and economic considerations, the UNFC aligns with global sustainability goals, including the 2030 Agenda for Sustainable Development (United Nations, 2015a) and the Paris Agreement (United Nations, 2015b). Its comprehensive framework supports decision-making processes across various sectors, facilitating efficient and responsible resource use globally. UNFC key features include a framework that covers all resources (minerals, petroleum, renewable energy, anthropogenic resources, injection projects, nuclear fuels, groundwater), sustainable development and alignment with SDGs and the Paris Agreement (United Nations, 2015a, b) and standardization, ensuring consistency and transparency in resource classification. The UNFC is a resource project-based and principles-based classification system for defining the environmental-socio-economic viability and technical feasibility of projects to develop resources. It provides a consistent framework to describe the level of confidence of the future quantities to be produced by the project (UNECE, 2020).

NGSO have participated in several national and international projects on UNFC implementation (e.g., the EU-funded MINVENTORY, ORAMA, GeoERA, MINEA), developing the knowledge and skills for different commodity types. Those projects served as a sound base to continue building a comprehensive knowledge base, share experience with the UNFC, and begin preparation for the joint European-level application of the UNFC. A baseline assessment was performed in 2023 amongst NGSOs to prepare for a common and consistent application of the UNFC, aligning with requirements of the CRM Act.

Some selected recommendations based on solutions for recognized barriers include awareness of the UNFC implementation benefits (for NGSOs as well as the authorities), capacity-building at different levels for different stakeholders, and proper communication between stakeholders. Furthermore, the translation of relevant UNECE documents, e.g., UNFC 2019 and Guidance Europe to national languages, could facilitate UNFC implementation (Horváth *et al.*, 2023). In recent years, the network of European NGSOs has developed considerable expertise and skills in UNFC practice and will play an important role in future capacity-building and its implementation and use.

A GEOLOGICAL SERVICE FOR EUROPE

What is a Geological Service for Europe and why do we need it?

Sustainable management of natural resources from the subsurface – not just raw materials and CRMs but also, for instance, groundwater, geo-energy, and energy storage solutions – is essential in delivering the EU's net zero 2050

target and UN Sustainable Development Goals. This crucial role of sustainable subsurface management for achieving policy targets is recognized in the requirements of the CRM and NZI Acts. Both Acts require Member State delivery of subsurface (geological) data (e.g., NEPs, characterization of secondary raw materials deposits, subsurface data from decommissioned petroleum production sites) to achieve near- to medium-term benchmarks underpinning the EU's ambitions for strategic autonomy, resilient value chains, and the growth of a net zero industrial base. In addition, the 2023 revision of the Renewable Energy Directive targets a ≥32% share of renewables in the EU's final energy consumption by 2030, which will also require increased uptake in deployment of geothermal energy from the subsurface.

These policy and regulatory targets must be underpinned by subsurface data, research, and expert advice. Meanwhile, increased and competing uses of the surface and subsurface require action to achieve – in parallel – sustainable management of European groundwater and soil, which are also crucial resources for agriculture, human health, and sustainable ecosystems but which are under increasing threats (e.g., Panagos *et al*., 2022; European Environment Agency, 2024). The climate changes that contribute to these interlinked anthropogenic and environmental pressures are similarly responsible for increasing geohazards (e.g., landslides, extreme flooding and drought), which have major social, environmental and economic impacts, and which are occurring with increasing frequency and intensity at regional to European scale.

Sustainable management of diverse – and interlinked – subsurface resources, environments, and hazards requires European-scale action: it cannot be effectively addressed only at national level. However, there is currently no sustained European-level initiative that is mandated or resourced to provide data harmonized at European scale, cross-border or European-scale programmes or analyses: this geoscience-based institutional European service to support European policy development and to national level implementation and reporting is missing. This is the role of a Geological Service for Europe.

Achieving sustainable management of Europe's subsurface is a complex multi-disciplinary task requiring a holistic view and multi-sectoral coordination. It requires tackling increasing climate and anthropogenic pressures, while making rapid changes in socio-economic, technological and environmental systems. Successful sustainable subsurface management requires not only European-scale policy implementation but also, underpinning such policy, European-scale:

- data acquisition, harmonization, management, delivery, and expert assessment;
- research and innovation;
- knowledge sharing;
- implementation of common methods;
- mature geoscience-policy partnerships.

The availability of data, and interconnections with research and expert services provided by a Geological Service for Europe, will enhance cross-border collaboration and pan-European knowledge sharing, speed up data collection, analysis, and reporting, and provide sound European-scale understanding of the geology underpinning diverse sectors that must transition to new low-carbon systems in the coming crucial few years. The role of the NGSOs, in advising their governments on subsurface management and providing information to the public, requires diverse skills. Considering the pressures facing Europe relating to climate change and natural resources, this knowledge and expertise must be scaled up to a European service that would facilitate data uptake, research and innovation (R&I), and advisory-based solutions at industry, policy and legislative level.

The ultimate objective of a Geological Service for Europe is to harmonize – at European level – national geoscience data, R&I, and expert advisory activities concerning surface and subsurface resources, environments, and hazards. This will support effective and timely implementation of the European Green Deal Industrial Plan and related national and European legislation and policy, such as that regarding CRM, energy, groundwater, soils, and geohazards. In targeting this objective, the Geological Service for Europe will benefit from the unique position of the NGSOs as the national authorities mandated to collect, archive and deliver data, information, and knowledge of all aspects of the geological surface and subsurface. This future Geological Service for Europe will benefit from the foundational work of the NGSOs in data collection, R&I, and their long-running collaboration through EuroGeoSurveys – the association of the Geological Surveys of Europe – as well as strong connections to academia, industry, and other government authorities and agencies. The positioning of the NGSOs and EuroGeoSurveys between sectors at national and European level will deliver a future Geological Service for Europe – a unique opportunity to accelerate the energy transition by bridging data collection, R&I, applied geoscience, and advising on legislative and industrial application of subsurface knowledge.

The potential impacts of a Geological Service for Europe, specific to CRM autonomy, include:

- Increased availability, connectivity, and use of CRM data;
- Increased transnational alignment of geoscientific approaches and collaboration;
- Application of CRM data across sectors using a consistent knowledge base, reducing regulatory siloing;
- More holistic treatment of data and knowledge in competing and multiple subsurface uses, allowing improved prioritization of subsurface use and management;
- Increased public acceptance of CRM exploration and mining;
- Strengthened international partnerships for security of supplies;
- Common national standards and approaches applied to European-level reporting and support to national-level implementation and reporting;
- Acceleration of industrial technology;
- De-risking and acceleration of project deployment;
- Sustainable management of geological data at European scale.

The road to a Geological Service for Europe

Collaborations between NGSOs, to compile and harmonize mineral resources data at the scale of Europe, have been initiated in recent years, through collaborative projects funded by successive EU framework programs. These projects allowed the development of data infrastructures, methodologies for data provision and harmonization, and – as such – have paved the way for a future Geological Service for Europe.

Among them, the ProMine project developed the first pan-European databases for mineral resources (Cassard *et al.*, 2015). The ProMine Mineral Deposits (MD) database, dedicated to primary mineral resources, described ~13,000 showings, occurrences, deposits, and mines in 34 European countries. The description of these records included general information, geology, mineralogy, morphology and ages of the ore and host rocks, tonnages and grades of resources, reserves and past production, and more. The ProMine Anthropogenic Concentrations (ACs) related to mining and metallurgical industries contained ~3,400 records of wastes, including mine wastes and unprocessed products (e.g., run-of-mine ore, unprocessed ore stockpiles, mine waste dumps, barren overburden), ore processing wastes (e.g., cobbing wastes, wash tailings, flotation tailings, leach residues, magnetic-separation tailings) and treatment wastes (e.g., smelter wastes, flue dusts, roasting residues, chemical treatment wastes, leach tailings, ashes, cocking plant residues, and more). These databases were a great step forward, offering compilations of primary and secondary mineral resources data at the scale of Europe, described with common data models and lexicons. The ProMine MD database allowed the production of the first maps of CRM deposits in Europe (Bertrand *et al.*, 2016), based on the first lists of CRMs issued by the European Commission (2011, 2014, 2017).

Despite the huge progress of the ProMine databases, their weakness was their static structure. Their update was not planned after the life of the project. To address this, the Minerals4EU project (2014–2015) had the objective of taking the ProMine MD database further by developing an IT infrastructure to allow its regular update. Minerals4EU developed a harvesting system that could query web services set up by national data providers (i.e., NGSO) to collect their data in a common INSPIRE format. The data was compiled in a unique pan-European database. In parallel, the European Geological Data Infrastructure (EGDI) web portal was developed to provide pan-European geoscientific data, among which is the Minerals4EU common database on mineral resources. The possibility to collect updated data from all national providers on a regular basis was again a great step forward. However, that generated gaps in data provision as some providers were lacking resources or expertise, or both, to develop their national mineral deposits database, its translation in the common format, or an operational web service to be harvested.

In the following years, several EU-funded projects developed knowledge on mineral resources at European scale (e.g., EuRare on rare earth elements, MSP-REFRAM on refractory metals, RESEERVE on the mineral potential of western Balkan countries, ProSUM on secondary raw materials). The GeoERA-FRAME project went further: in addition to compiling mineral resources data at European scale (for lithium, cobalt, niobium, tantalum, rare earth elements, phosphate rocks and natural graphite), it developed added-value products to valorise that data. This included data-driven mineral prospectivity maps showing spatial distribution of geological favourability by commodity (Bertrand *et al.*, 2021) and expert-guided maps of metallogenic potential, highlighting areas with the highest potential for a given

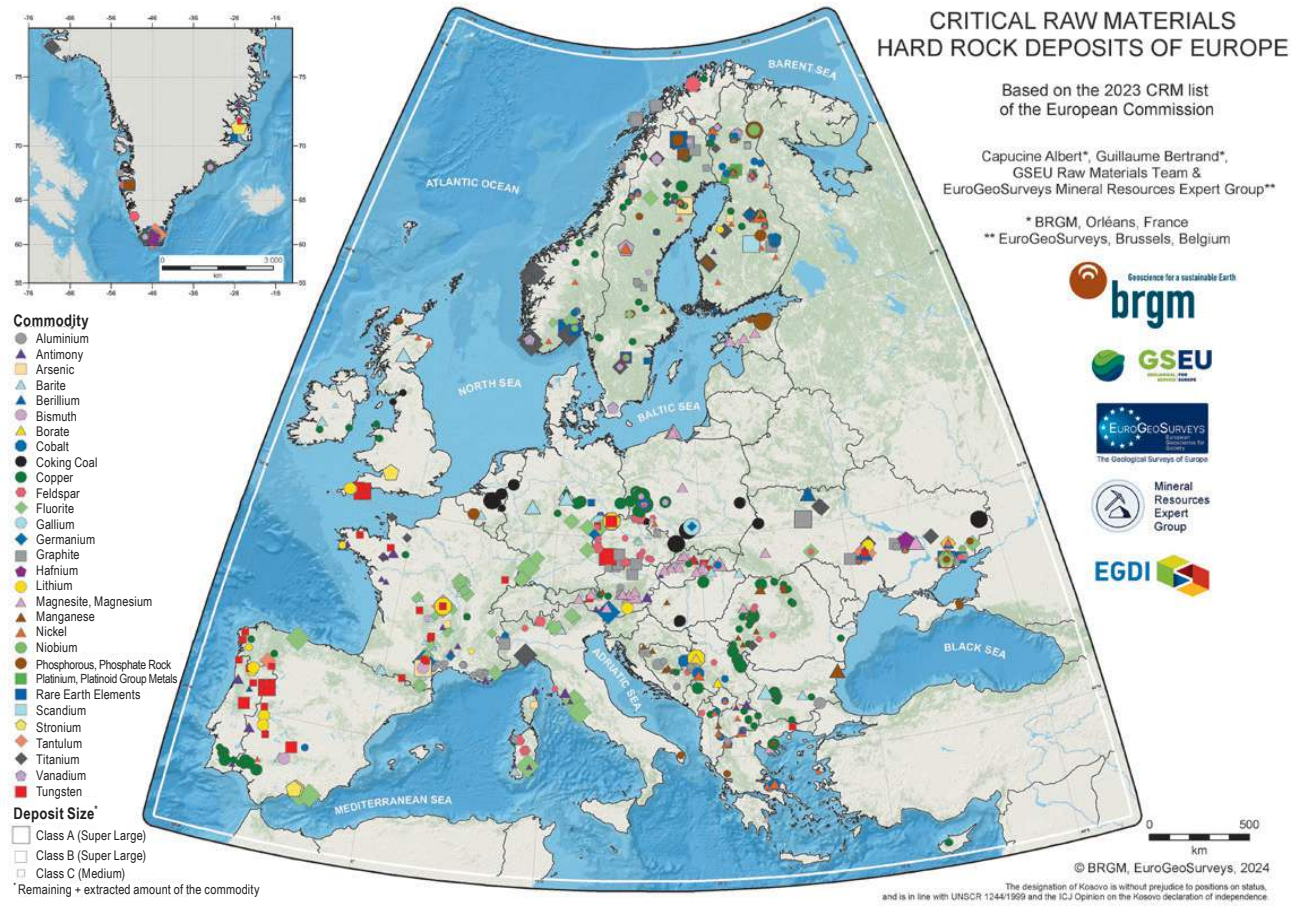

Fig. 2. The 2024 map of CRM hard rock deposits of Europe, a deliverable of the Geological Service for Europe project

deposit type (Sadeghi *et al*., 2020). A positive aspect of these maps was to provide a global and harmonized view of the European continent, allowing comparison of geological endowment and potential for mineral resources.

Despite these outputs, a problem with these projects was that – except for RESEERVE – they all built their own database, without perennial funding to maintain the database after the project life. This resulted in a multiplication of datasets with diverse contents, formats, and models. As a result, the initial objective of building a single database on mineral resources was compromised.

The GeoERA-Mintell4EU project further developed the central database (now called MIN4EU) as part of EGDI and included new countries and the Minerals Yearbook, with statistical data about production, import/export, and so on.

Multiplying databases on the same topics results in complex and dispersed mineral resources data organization in Europe, which is difficult for non-expert end-users to understand and use. This situation highlights, more than ever, the need for a unique, harmonized and regularly updated pan-European mineral resources database. This compilation and update should involve all national data providers. The infrastructure is in place centrally through the MIN4EU database of EGDI, but there are still technical and organizational challenges in several of the data-providing institutions. It is indeed a complex technical and organizational process and must be centralized within a Geological Service for Europe, a central service with sufficient resources and authority. Since 2022, the GSEU – Geological Service for Europe project – actively works on involving all European data providers to compile mineral resources data, technically, and geographically harmonized at the scale of Europe. The GSEU project is also working towards establishing the Geological Service for Europe that will maintain this effort after the lifetime of the project.

Raw Materials in a Geological Service for Europe

NGSOs have national mandates to deliver knowledge of the geology (including the mineral resource potential) of their territories, to inform policy and the public. However, these data are primarily designed to serve national and regional requirements, and they are typically described and organized differently from one country to the next due to different geological contexts, geoscientific practices and traditions, and regulatory frameworks. Enhancing the knowledge of mineral potential in Europe requires us to mitigate these disparities, e.g., through the trans-border cooperation and knowledge sharing that has been ongoing through the EuroGeoSurveys Mineral Resources Expert Group for many years, and through their many collaborative projects.

Since 2010, there have been significant efforts and cooperation within the European NGSO community to share and harmonize parts of their data on raw materials to an interoperable pan-European format (see Wittenberg *et al.*, 2022 for a review of past EU projects). This has led to the development of the permanent central digital platform EGDI, with a sustainable operating service that aims to provide a single access point to unified pan-European datasets and geological services. At the core of this data collection system, the network of NGSOs provides information on primary and secondary continental and marine resource data in Europe in compliance with the INSPIRE Directive (see European Commission, 2007), which aims to standardize geospatial data across borders, ensuring interoperability. These efforts have delivered multiple datasets on mineral occurrences and mines (the Minerals Inventory), aggregated data on production, trade, resources and reserves (the electronic Minerals Yearbook), as well as innovative products such as maps of areas of higher mineral potential through predictive targeting (Jorgensen *et al*., 2023). These past European projects have also brought to light some long-standing challenges related to data availability, geographical coverage, accessibility, harmonization, data quality, specifically:

Data repository: While most NGSO host data on raw materials in a central national database, several countries still do not have such repository, and instead deliver tailor-made data on a project-by-project basis. Solutions are urgently required to mandate NGSOs to develop such databases and cover the geographical gaps.

Resources: are unevenly distributed among NGSOs and the level of knowledge and competences is equally variable. Additionally, not all NGSOs have access to the same technological capabilities or level of information, leading to disparities in the quality of data and monitoring. Although NGSOs have the most comprehensive expertise for the collection of mineral resource data, updating and maintaining it require sustained funding to ensure data continuity and robustness.

Data fragmentation: Despite the efforts of several initiatives, a lack of harmonization in classification and reporting of geological and mining data across countries is still evident. Adoption of shared standards for reporting remains slow due to the complexity of aligning different national systems. This involves both technical hurdles, such as ensuring compatible data formats and platforms, and legal considerations, such as data sharing agreements and intellectual property rights. Extensive technical training is needed to ensure a common understanding and the systematic collection of harmonized information.

Data and maps: require regular updates. Sustainability and improvement of the data and associated maps require that all contributors ensure their data are part of their national database and are kept up to date so they can be regularly automatically collected and transferred to the central EU database. The acquisition of resources and reserves data is a time-consuming and resource-intensive process, complicated by confidentiality issues and the lack of reporting requirements for unlisted companies and/or in certain countries. So far, only a handful of NGSOs have established a routine procedure to update their national inventories. Commitment is required from all NGSOs to maintain more continuous (annual) and timely updates.

These efforts are essential for Europe's sustainable resource management, particularly in the context of the ongoing energy transition and the need to secure CRMs for the future. Confronted with these challenges, never has it been more important to understand, define, and document the mineral potential of Europe, and never has the need for increased capacity and collaboration between NGSOs been stronger. This is where the relevance of pan-European geological services to support European raw materials resilience becomes clear: this is a key part of the vision of EuroGeoSurveys to deliver the required interconnected data, R&I, and advisory support through a Geological Service for Europe.

Raw Materials in a new Strategic Research and Innovation Agenda delivered through a Geological Service for Europe

EuroGeoSurveys has delivered a new Strategic Research and Innovation Agenda (SRIA; EuroGeoSurveys, 2025) to target the geoscientific research and innovation (R&I) goals, priorities, and actions to support achieving the energy transition while building European competitiveness. The SRIA is centred on geoscientific data and knowledge of Europe's subsurface to address key European and global challenges, including climate change, energy security, and resource sustainability. The SRIA serves as the scientific foundation for the vision of EuroGeoSurveys to establish a Geological Service for Europe – a permanent, sustainable and data-driven service that will provide critical geoscientific insights for European policymakers, industries, and citizens. The R&I vision of this document is founded in, first and foremost, the geoscientific (data, vocabularies, maps and models) and digital framework (EGDI) required to support all other geoscientific thematic R&I goals addressing sustainable management of the European subsurface. These thematic goals include energy transition and decarbonisation, sustainable management of groundwater, managing geohazards and environmental risks, and responsible raw materials. The targeted R&I actions foreseen under the latter goal, which addresses CRMs in particular, are outlined below.

Given the multifaceted challenges surrounding mineral resources, and the objectives outlined in the CRM Act, EuroGeoSurveys have prioritized three key areas.

Support Raw Materials Exploration to Assess European Potential. Support for exploration efforts is needed to accurately assess Europe's mineral resource potential, which is a key ambition of the CRM Act. This requires the development and maintenance of standardized, harmonized databases at the European level, adhering to established standards such as UNFC and INSPIRE. Harmonizing lithotectonic units and identifying European mineral provinces is crucial, as is a better understanding of ore formation processes, enabling identification of exploration targets. These insights will be further explored using machine-learning and artificial Intelligence to identify areas with specific characteristics indicative of favourable mineralization environments. Predictive 3D models integrating geological structures and their geometry should be developed and used as tools for identifying or confirming high-potential areas at depth or beneath cover. The availability of advanced tools and technological advances (e.g., in geophysics, geochemistry, drilling methods) will undoubtedly enhance research capabilities and expand knowledge. Contemporary mineral resource exploration also requires a thorough understanding of unconventional deposits, such as brines and submarine deposits. Given the limited knowledge of submarine mineral resource formation processes, technological advances and innovation are essential for understanding these complex

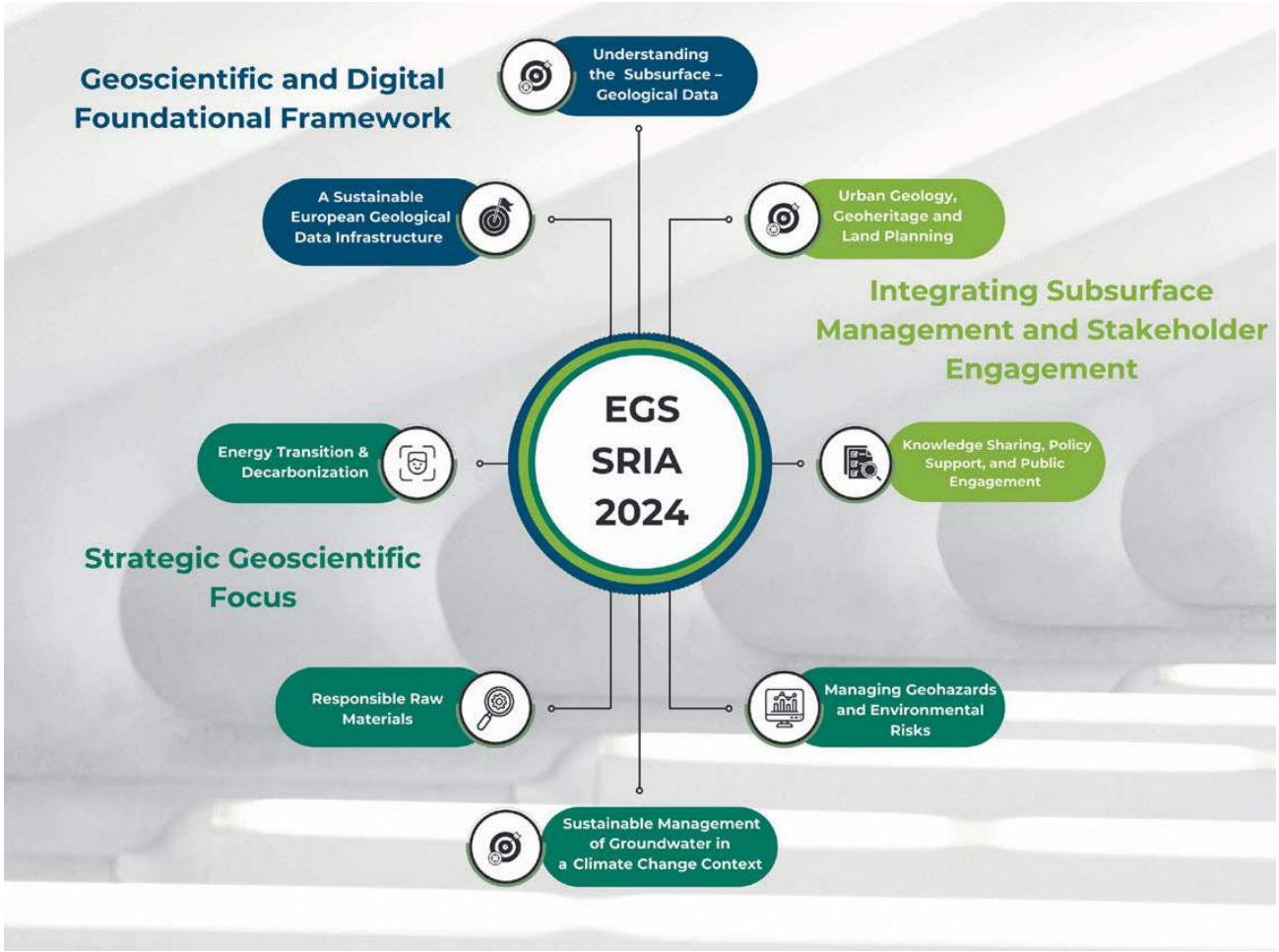

Fig. 3. The structure of the EuroGeoSurveys 2025 Strategic Research and Innovation Agenda, defining the geoscientific R&I challenges foreseen to support the energy transition while building European competitiveness

systems. The SRIA underscores the importance of collaborative efforts with diverse stakeholders including universities, technology companies, and industry, to drive R&I in this area. Pilot projects should also be established to jointly test and develop novel methodologies and tools while prioritizing environmental considerations.

Improve Responsible Supply of Raw Materials in Europe. This priority entails a comprehensive assessment of the entire mineral resource life cycle, from exploration to recycling or landfilling, encompassing all stages of exploration, extraction, production, and use. It is imperative to develop, refine and share models that take account of diverse scenarios to gain a deeper understanding and to analyse workflows. Providing up-to-date criticality assessment tools is crucial for guiding informed policy decisions. There is also a need to integrate social sciences into research methodologies to address the significant social and environmental challenges prevalent in the raw materials sector (e.g., social license to operate). To achieve these objectives, NGSOs are committed to establishing or strengthening collaborations with various organizations, including national-level Raw Material Observatories, and fostering partnerships in R&I to enhance data integrity and reliability. Collaborations with other organisations and institutions are also essential for addressing the social component.

Support development of responsible mining and a circular economy. Innovation in mine monitoring and control techniques, such as the use of earth observation tools and unmanned aerial vehicles, can significantly enhance monitoring capabilities and mitigate environmental impacts. Systematic characterization and continuous refinement of methods to accurately define mining waste (considering factors such as volume, quantity, and associated environmental risks) are indispensable for achieving the objectives outlined in the CRM Act. Maintaining up-to-date databases on mining waste and secondary deposit potential is equally critical. Furthermore, R&I in the treatment of secondary deposits and mining waste is a priority to improve resource recovery from low-grade sources. Collaborative pilot projects with industry and research organizations are strongly recommended in this area.

To realize European ambitions for resilient raw materials value chains, addressing the diverse and complex challenges requires a concerted effort. NGSOs play a pivotal role in advancing our understanding of the subsurface and sharing this valuable knowledge with stakeholders involved in mineral resources R&I.

The European International Centre of Excellence for Sustainable Resource Management

A common understanding and knowledge of European resources, as well as their sustainable management, is required to support the European Green Deal (European Commission, 2019) and the implementation of the CRM Act. The European Commission's ambitious vision for a healthy planet and a climate-neutral economy, as well as actions needed for the achievement of the Sustainable Development Goals (SDGs) (United Nations, 2015a) rely on raw materials knowledge more than ever before.

The UNECE has responded to the requirement for sustainable resources within the 2030 Agenda for Sustainable Development (United Nations, 2015a) and the Paris Agreement (United Nations, 2015b) via the implementation of the International Centres of Excellence on Sustainable Resource Management (ICE-SRM), a collaborative network of organisations focused on supporting sustainable resources management.

The establishment of an EU International Centre of Excellence on Sustainable Resource Management (EU ICE SRM) within the Geological Service for Europe is therefore a direct response to supporting the implementation of the CRM Act and the sustainable resource management needed to secure the supply of resources necessary to achieve the Green Deal, Digital Transition, and follow the Sustainable Development Goals.

The EU ICE SRM will be a capacity-building and promotion centre to support the United Nations Resource Management System (UNRMS) aligned with the United Nations Agenda 2030 SDGs. The EU ICE SRM will support stakeholders (EU, national and regional governments, and decision makers, NGSO, industry, etc.) in their development in line with the 2030 Agenda for Sustainable Development and the Paris Agreement. The centre will build its expertise using networks of partners, experts, and stakeholders to support stakeholders in the field of resource management at national, regional, and European level. The work of the centre will be supported by a knowledge platform (EU ICE SRM IT Platform). The EU ICE SRM intends to become a part of the UNECE ICE-SRM network, by following the Terms of Reference and Criteria for Designation set by the UNECE Expert Group on Resource Management (EGRM).

Although not yet fully established, the EU ICE SRM has already begun the required capacity building to support knowledge and deployment of UNFC, and to accelerate the implementation of the CRM Act, focusing primarily on the reporting on NEPs. In 2024, a 'Train the Trainer' course was designed with the aim of forming a network of UNFC trainers at NGSOs, which will be able to share knowledge further, through training, at national level. Training procedures were designed by 12 trainers, project partners, and UNFC experts who are actively involved also in the UNECE Expert Group for Resource Management, Network of Practitioners Europe, and UNFC Adoption Group. The training procedures were designed in a three-level approach, increasing and deepening the knowledge from level 1 to level 3. In level 1 training, a basic knowledge of UNFC was presented, with the training being appropriate for everyone. Training levels 2 and level 3 gave deeper insights into the use (level 2) and teaching (level 3) of UNFC. The training was performed from April to June 2024 and 44 participants were trained from 20 European countries, who are now spreading the knowledge of UNFC implementation further at national level.

The EU ICE SRM is in the process of development and has already begun performing its activities in parallel with the process of its organization and establishment.

The European Geological Data Infrastructure

The European Geological Data Infrastructure (EGDI), was established in 2016 with the primary purpose of establishing a one-stop shop for results from European, scientific, geological projects, primarily with the participation of EuroGeoSurveys members. The EGDI was originally conceptualized through the EU-funded EGDI Scope project (https://www.egdi-scope.eu/), which reported that results from around 80 EU-funded projects, with a total budget 400–700 M€, were already "lost" or were about to be "lost"

because there normally was no obligation for the project participants to maintain project websites and databases for more than a few years following project completion. The initial version of the EGDI contained results from 13 projects under 5 geoscientific topics and it enabled the users to show and combine the many map layers on a web GIS. It also included a metadatabase with structured and important information about all the map layers.

This first version of EGDI was developed and financed by members of the EuroGeoSurveys Spatial Information Expert Group. During the proposal phase for the GeoERA programme, it was decided to use the EGDI as the IT platform for all results from the GeoERA projects. A dedicated GeoERA project, called GIP-P, was included in the programme with the focus of extending the EGDI to be able to store and disseminate the results from the other 14 geoscientific GeoERA projects.

The GIP-P project resulted in the development of the following functionality and data:

- A document repository with reports, images, smaller databases, *etc*.;
- A 3D geological model database and viewer;
- A vocabulary for terms defined in the projects;
- A multilingual keyword thesaurus;
- A free text search system, using the content in the map database, the vocabularies, the keyword thesaurus and the metadata catalogue;
- An e-learning platform;
- A user support system;
- A system for showing the status of all services offered by EGDI.

On completion of the GeoERA project, ~800 layers and ~1,300 documents from 52 projects were available in the EGDI, which also contained over 8,000 scientific concepts and more than 2,600 geoscientific terms in 21 languages in the keyword thesaurus. The GIP-P project put a lot of emphasis on helping the other GeoERA projects to use European and international standards for their data products, thereby making those as FAIR as possible.

Particular focus was placed on collaboration with the Mintell4EU project, which delivered data on mineral deposits, mines and the Minerals Yearbook, with statistical data on mineral production, export/import, and similar topics. A harvesting system was established to collect data from the NGSOs to the central MIN4EU database. In that way, it was made possible to show updated information about CRMs and other important commodities on the EGDI very soon after new data had been included in national databases.

The GIP-P project also established some services specifically aimed at supplying information about CRM deposits to the European Commission Joint Research Centre's Raw Materials Information System platform.

The EGDI was subsequently chosen as the IT platform for the GSEU project, and a specific work package was included in that project to focus on the further development of the EGDI with three main goals:

- **Support to the geoscientific work packages** in standardising, safeguarding, and disseminating their results. In the area of mineral resources, the focus is primarily on marine deposits and how they are organised and disseminated to be compatible with the onshore data, and on collecting, storing, and disseminating data on UNFC classifications for mineral resources;
- **Technical standardization** of the EGDI so that it can be connected to other infrastructures as smoothly as possible, building on the FAIR principles;
- **Extend functionality of the EGDI** to include elements of knowledge in addition to data and information. This includes expertise, projects, infrastructures, etc. from the NGSOs and will support the UNFC ICE SRM, and the Knowledge and Competence Hub for Sustainable Geo-Energy Capacities.

In the GSEU project, the EGDI is also being developed in the following areas:

- The free text search system;
- The map viewer;
- The MIN4EU harvesting system;
- The EGDI services, where the Open Geospatial Consortium Application Programming Interface will be included;
- The use of a Fraunhofer Open Source SensorThings (FROST) server to obtain a higher degree of FAIRness;
- The storage, visualisation, and uploading of 3D geological models;
- Further automation of the data flow related to mineral resources;
- A redesigned multilingual website.

The EGDI has been central to EuroGeoSurvey's strategy in the last decade and is also a fundamental and tangible element in the future Geological Service for Europe.

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