Mineral Economics
https://doi.org/10.1007/s13563-025-00552-4

ORIGINAL PAPER

Applying the United Nations Framework Classification for Resources for a national raw materials inventory in Italy

Ghadi Sabra[1] · **Slavko Solar**[2] · **Gian Andrea Blengini**[1,3]

Received: 23 July 2025 / Accepted: 16 September 2025

Abstract
The increasing demand for critical raw materials (CRMs) driven by the green and digital transitions calls for the implementation of a robust resource management framework across Europe. Similarly to other EU Member States, Italy faces challenges in managing the inventory of its mineral resources, stemming mainly from in-homogeneous and discontinued data collection, in the absence of a specific classification and reporting system adopted at national level. The implementation of a coherent and centralized data collection and classification system could help improve the currently fragmented regional reporting practices, in turn supporting Italy to contribute to the objectives of the EU Critical Raw Materials Act (CRMA). Resource classification is important to resource management, serving as one of the foundations for collecting, analyzing, and communicating data on resources, presenting data into information for decision-making and policy formulation. The United Nations Framework Classifications for Resources (UNFC) offers a standardized approach that bridges current gaps in classification, and reporting practices. This paper pursues the objectives of assessing the applicability of UNFC in Italy using publicly available data. Besides demonstrating the applicability of UNFC in Italy, the findings support a shift towards standardized, policy-relevant resource classification for a sustainable and transparent resource management system, by classifying the raw materials projects in UNFC, and furthermore the development of a UNFC-based Italian national raw materials inventory.

Keywords Resource classification · UNFC · Critical raw materials · Raw materials inventories

Introduction

The European Union (EU) is navigating an era of unprecedented challenges. The quest to deliver on the objectives set by the Green Deal and the Digital Transition, as well as the Paris Agreement and the United Nations 2030 Agenda for Sustainable Development, fundamentally depends on a sustainable and secured supply of raw materials, especially Critical Raw Materials (CRMs). CRMs are the building blocks for strategic sectors, such as green technologies, digital infrastructure, defense applications (European Commission 2024). This transition to a low-carbon economy is projected to increase the demand for CRMs (IEA 2025), though the scale of growth for a range of raw materials remains highly uncertain and varies across different scenarios (Naegler, et al. 2025). However, known reserves and resources of these materials represent only a small fraction of the quantities projected to be needed in the coming decades (IEA 2021). Meeting this demand will rely heavily on intensified exploration and research, which in turn require substantial investments, cutting-edge geoscientific capabilities, and robust industry-academia collaboration. The discovery of new ore deposits, particularly those with complex geology and processing challenges, will depend on coordinated research efforts that integrate advanced mineral systems understanding with the development of more

✉ Ghadi Sabra
ghadi.sabra@polito.it

Slavko Solar
Slavko.Solar@GEO-ZS.SI

Gian Andrea Blengini
giovanniandrea.blengini@unito.it

[1] Dipartimento di Ingeneria dell'Ambiente, del Territorio e delle Infrastrutture (DIATI), Polytechnic University of Turin, Turin, Italy

[2] Geological Survey of Slovenia, Ljubljana, Slovenia

[3] Department of Earth Sciences (DST), University of Turin, Turin, Italy

Published online: 23 October 2025

efficient and environmentally sound extraction technologies (Marlatt 2020).

As demand for CRMs grows, the EU's ability to ensure long-term supply security hinges not only on diversification of importing countries and international partnerships but also on improving domestic capacity, both based on sustainable resource management practices. At the heart of such practices lies an important enabler: *resource classification*. Sustainable resource management requires consistent, coherent, and transparent information on the availability, recoverability, and viability of natural resources (UNECE 2020). It is through classification that raw material data become actionable information, potentially guiding decision-making across exploration, investment, permitting, and policy development. The role of classification is particularly pronounced in Europe, where multiple national systems and international codes exist. EU Member States rely on a variety of systems, including codes from the Committee for Mineral Reserves International Reporting Standards (CRIRSCO) (e.g., JORC, PERC, NI 43–101), the United Nations Framework Classification for Resources (UNFC), legacy systems such as the Russian GKZ classification, and classification systems that are unique and only used within a certain jurisdiction (e.g., Austria or Czech Republic). This multiplicity complicates the interoperability of raw materials data across jurisdictions and hampers efforts to build a unified EU-wide resource intelligence base (Bide 2018). Since the EU Critical Raw Materials Act (CRMA) came into force in 2024, the need to harmonize national inventories and align them with European strategic goals has become increasingly urgent (European Commission 2024).

Italy, one of the largest manufacturing economies in the EU, with several CRMs-reliant industrial sectors e.g., automotive), is in the process of aligning with resource management practices. Its raw material governance landscape is fragmented, as the mining legislations mainly exist at regional levels (Grandi 2019). Moreover, classification and reporting systems vary across regions and provinces, data is often confidential or inaccessible, and there is no national-level framework for consistent classification or public reporting of mineral projects. These are the main bottlenecks to be tackled in order to boost Italy's capacity to assess domestic supply opportunities and meaningfully contribute to the EU's raw materials agenda.

The speed at which demand is accelerating may exceed the mining sector's ability to respond under conventional market conditions. This could necessitate interim policies such as the development of less economically attractive deposits under national or private-public ownership models, to ensure security of supply during this transitional period. Therefore, it is beneficial for authorities to establish a raw materials inventory of sources and products, with reliable and relevant information for decision-makers, to better evaluate such priorities (UNECE 2022). Italy's raw material potential must therefore be approached with a long-term strategy, anchored not only in geology, but also in governance and sustainability. As illustrated in Fig. 1, nonfuel minerals, CRMs for instance, contribute a large portion to the Italian economy, and is assumed to grow even larger in the upcoming years.

This paper aims to demonstrate the adoption of UNFC in Italy and show that such an adoption is both feasible and practical to manage. UNFC offers the possibility of integrating environmental-socio-economic viability (E axis), technical feasibility (F axis), and geological confidence (G axis) into classification, thereby addressing sustainability and policy concerns that are not solely on purely market- or commodity-driven systems (UNECE 2020; Wittenberg et al. 2024).

The specific objectives of this paper are:

1. Analyze the current state of raw materials classification, data availability, and collation of primary raw materials information in Italy, while highlighting challenges in terms of consistency, transparency, and policy integration;
2. Test the applicability of a UNFC in Italy on primary raw materials with data from different sources, harvested from (i) industry reporting, (ii) historic data, and (iii) extrapolated geological occurrences deduced from publicly available data and research and academic reports. The collected data ultimately contributed to a preliminary UNFC-based Italian raw materials inventory built from available sources.

The results are then used to discuss CRMs management in the context of CRMA, particularly by highlighting the importance of classifying and communicating domestic raw materials data in a consistent and policy-relevant manner. The paper aims to lay the groundwork and test how a harmonized national inventory of raw materials can contribute to the EU's collective strategic autonomy, sustainability, and resilience goals. Moreover, this study lies in its pioneering application of UNFC within the Italian context.

Critical raw materials policy landscape in Europe and Italy

UNFC in the EU critical raw materials act

CRMA is the EU's regulation to enhance EU's CRMs value chains and reduce dependencies on imports, especially from single third countries. Recent global crises

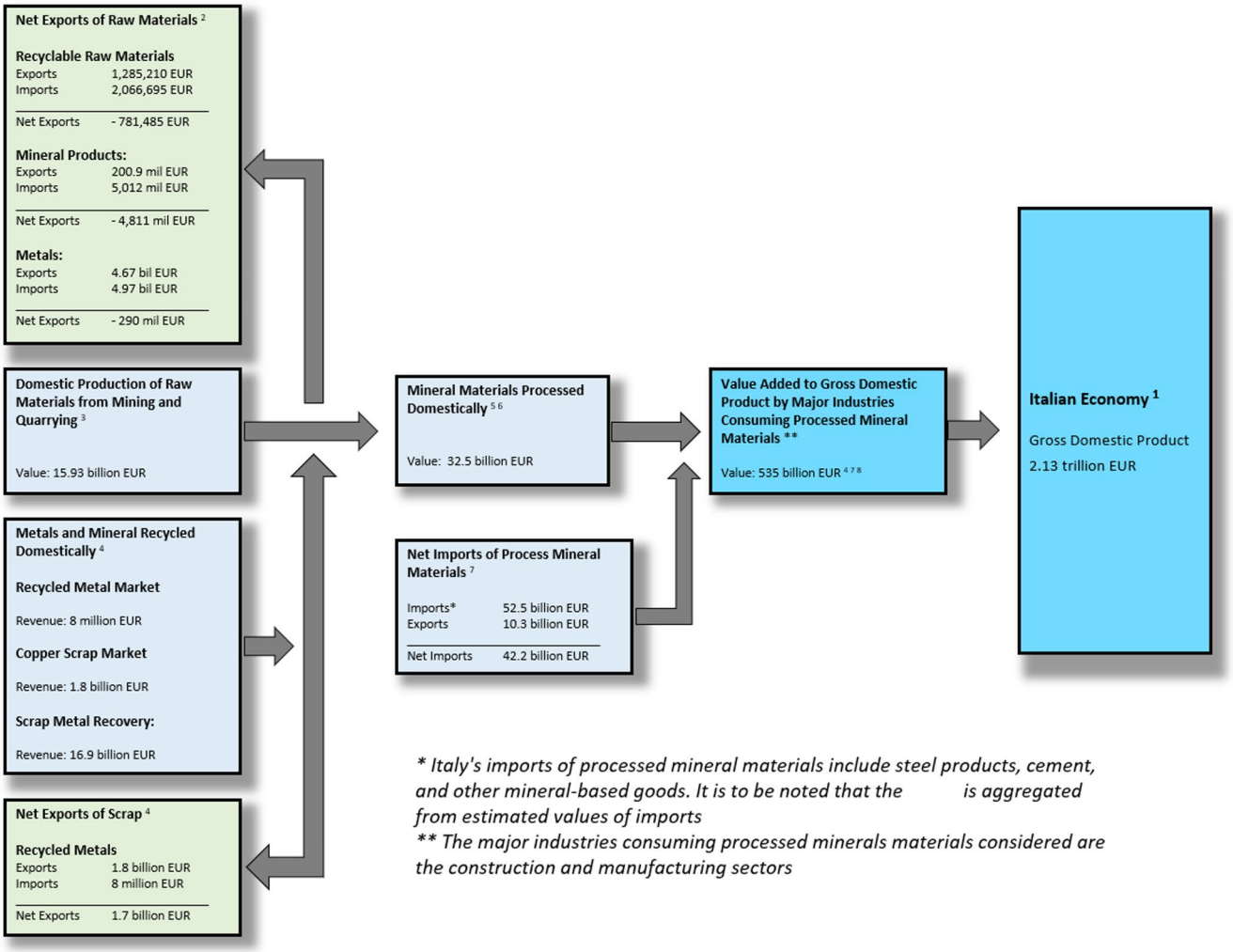


Fig. 1 The role of nonfuel minerals in the Italian economy, estimated values in 2023. 1USGS (2021) Methodology adopted and revised from the U.S. Geological Survey and U.S. Department of Commerce, Mineral commodity summaries 2021: U.S. Geological Survey, Figure 1. p.4, https://doi.org/10.3133/mcs2021. Reuters. (2024). Italy revises down 2023 GDP growth, budget deficit, debt. 2. Reuters. https://www.reuters.com/markets/europe/italy-revises-down-2023-gdp-growth-budget-deficit-debt-2024-09-23/. 3. Italian National Institute of Statistics (ISTAT) (2025). Mining and quarrying sector data. Esploradati. https://esploradati.istat.it/databrowser/#/en/dw/categories/IT1,Z0920ENV,1.0/DCCV_CAVE_MIN/IT1,9_951_DF_DCCV_CAVE_MIN_2,1.0. 4. Trading Economics (2025). Italy exports of non-metallic mineral processed products. https://tradingeconomics.com/italy/exports-of-non-metallic-mineral-processed-products. 5. GMK Center (2024). Italy imported 7.2 million tons of steel from third countries in 2023. https://gmk.center/en/news/italy-imported-7-2-million-tons-of-steel-from-third-countries-in-2023/. 6. Marmomacchine International (2024). Nel 2023 lieve flessione per l'export italiano di pietre naturali [Slight decline in Italian natural stone exports in 2023]. https://www.marmomacchineinternational.com/en/nel-2023-lieve-flessione-per-lexport-italiano-di-pietre-naturali/. 7. Statista (2025). Imports and exports of stone and mineral construction materials in Italy. https://www.statista.com/statistics/1417949/imports-and-exports-of-stone-and-mineral-construction-materials-italy/. 8 . Eurostat. (2025). Structural business statistics overview – Mining and quarrying. https://ec.europa.eu/eurostat/databrowser/view/sbs_sc_ovw/default/table?lang=en

have underscored Europe's vulnerability and the need for joint, timely action to protect the single market, support competitiveness, and secure the materials essential for achieving climate and digital transitions (European Union 2025). CRMA seeks to ensure the EU has strong, resilient, and sustainable CRM value chains by enhancing domestic capacities across extraction, processing, and recycling, diversifying sources of supply, and improving monitoring of risks and disruptions. To further these goals, CRMA sets specific benchmarks for Strategic Raw Materials (a subset of CRMs): at least 10% of annual EU consumption should come from domestic extraction, 40% from domestic processing, and 25% from recycling, with no more than 65% of any CRM supplied by a single third country. Alongside the Net Zero Industry Act, CRMA is also a pillar of the EU's Green Deal Industrial Plan (European Commission 2024).

A distinctive feature of CRMA is the integration of UNFC as the tool for resource classification and reporting

across the EU and beyond (in the case of Strategic Projects). UNFC offers a unified language for Member States to report in, while evaluating the sustainability, technical feasibility, and geological aspects of projects across the CRM value chain. UNFC is referenced under four articles in CRMA. First, it is mandated for use by Member States to report the results of their National Exploration Programmes (NEPs). Second, UNFC is to be applied for risk monitoring and stress testing on producing CRMs projects in EU. Third, UNFC is required for the classification of extractive waste from closed facilities, when applicable. Lastly, project promoters applying for Strategic Projects are required to classify their projects using UNFC. Moreover, the first call for Strategic Projects under CRMA received 157 projects in EU and in third countries, all classified in UNFC (European Commission 2025). UNFC supported in the technical assessment phase of these Strategic Projects proposals, in evaluating economic viability, technical feasibility, environmental and social aspects, and project readiness (European Commission 2024).

On the other hand, UNFC also supports the monitoring of project development over time. To this end, it supports CRMA objectives by making it possible to compare projects across different stages (from exploration to recycling), to assess sustainability, and to translate diverse reporting systems into a common format, without imposing additional burdens on users (Grohol 2024).

Collection of raw materials data in Italy

In the EU and elsewhere, a persistent obstacle to effective resource management is the issue of data confidentiality and inaccessibility. Reliable and consistent data acquisition is a fundamental element for national authorities to monitor and support sustainable resource management. Statutory reporting of raw materials, including resource and reserve estimations, exploration activities, and production, is an essential step to minimize geological information losses and to prevent non-active license holdings that delay development (European Commission 2024; Grandi 2019). Additionally, publicly listed companies are required to disclose exploration and production data to investors under international stock exchange rules (if listed). More recently, the increased emphasis on ESG (Environmental, Social and Governance) performance and sustainable finance has intensified demands for greater transparency in raw materials reporting. This aligns with societal expectations for shared value, social responsibility, and environmental stewardship between governments, local communities, and private sector actors in the extractive industries. Furthermore, global capital allocators increasingly demand ESG-aligned disclosure, influencing the availability of finance for exploration and mining projects (World Bank 2021).

Within Italy, the landscape of raw materials data collection and reporting is marked by institutional decentralization and regulatory heterogeneity. Responsibilities for primary raw materials management lie primarily with regional governments, reflecting the devolution of administrative functions set out in the Republic President's Decree of 24 July 1977, n.616 (articles 61 and 62) and the Legislative Decree of 31 March 1998, n.112 (articles 33–35). Under these provisions, regional authorities are entrusted with the governance of mineral and thermal waters, as well as quarries and peatlands. Moreover, regions may delegate specific responsibilities for exploration, evaluation, and development to provinces and municipalities, resulting in a patchwork of local governance arrangements. Raw materials data, especially for industrial and metallic minerals, is collected annually at the regional level through varying methodologies defined by local legislative frameworks. The data is stored and managed using diverse formats depending on the region (Parker 2015). Notably, the raw materials databases are not INSPIRE-compliant and rarely available in multilingual formats (Grandi 2019). Although the Instituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA), to which the geological survey of Italy is part of, maintains statistical datasets, such as the *Environmental Data Yearbook*, and a historical database of extraction activities from 1860 to 2007, national-level harmonization remains a significant challenge. The *Mining Map of Italy* (1:1,000,000 scale), produced in 1973, and more recent regional maps (e.g., Tuscany, Sardinia) provide valuable spatial data, but a consistent, up-to-date national mining cadaster is lacking (Servizio Geologico d'Italia 1973; ISPRA 2012). It is to be noted that, in light of the CRMA provisions on upscaling national exploration activities, ISPRA is implementing the new National Exploration Programme (Piano Esplorazione Nazionale), which aims to harvest and add up of further data on CRMs in Italy (ISPRA 2025). Complementary economic and financial data is gathered by ISTAT (Italian National Institute of Statistics) (Parker 2015).

Currently, there is no unified national standard or internationally recognized classification system used systematically across Italian regions for resource and reserve reporting. As such, raw materials information in Italy remains fragmented, with varied terminology, inconsistent collection intervals, and non-harmonized formats (Grandi 2019). Exploration companies are legally required to report resource and reserve data to the respective regional authorities, and most regions have implemented Regional Plans for Extractive Activities (PRAE), which aim to manage the full extraction lifecycle, from site identification through extraction to post-closure remediation, while balancing natural resource use

and environmental protection. However, the PRAE implementation and legislative underpinning differ significantly between regions (Grandi 2019). On another note, ISPRA, in collaboration with ISTAT and under the guidance of the Ministry of Industry and Made in Italy (MIMIT), is working on a national harmonized census of mining activities (Fumanti 2023). The objective is to standardize data collection from quarries and mines based on international reporting codes such as the UNFC or CRIRSCO-aligned standards (Grandi 2019). This initiative acknowledges the urgent need to integrate national raw materials data into broader European and international classification and reporting systems, especially in light of CRMA (European Commission 2024). The roles and responsibilities related to raw materials data collection and management in Italy are summarized in Fig. 2.

Implementation measures for CRMA in Italy

In response to CRMA and EU Regulation 2024/1252, Italy has taken a legislative step by adopting Decree-Law No. 84 (D.L. 84/2024) of 25 June 2024. This urgent legislative measure seeks to strengthen national capacities for ensuring the secure and sustainable supply of CRMs of strategic interest, while aligning Italy's domestic framework with European objectives.

The decree, composed of 17 articles, includes a comprehensive national strategy across the CRM value chain, from exploration and extraction to processing, investment, export control, and governance. In essence, D.L. 84/2024 would serve as a blueprint for Italy's national CRM strategy, bridging the policy gap between EU expectations and national capacities. The provisions on CRMs of strategic interest and their relevant implications, as well as whether they pertain to UNFC are summarized in the Table 1 (Senato della Repubblica 2024).

Methodology

UNFC application

Resource classification is defined as a structured process for assigning potentially recoverable resources to appropriate categories based on their environmental, social, economic viability and technical feasibility. It involves a sequence of steps starting with information collection, quality assurance, evaluation, classification, and lastly reporting. These steps are aimed at supporting resource development under conditions of uncertainty (Speirs et al. 2015; McKelvey 1972). While a perfect classification system would offer error-free assessments, the inherent geological complexity and

ISRPA / ISTAT	Arranging Harmonized mining census across Italy based on international standard codes, in collaboration with MIMIT
Ministry of Industry and Made in Italy (MIMIT)	Supports regional policies for raw materials exploitation; collaboration on defining minerals in line with EU policies
Exploration Companies	Reports resource and reserve data for regional territories, required by statutory obligation
ISTAT	Gathers economic, financial, and statistical mining data; collaborates with ISPRA for national harmonized mining activity census
Geological Survey of Italy (ISPRA)	Collects statistical data on mining and quarrying activities; maintains data on industrial and metallic mineral extraction; collaborates with ISTAT for mining census using international codes
National Government	Jurisdiction on mining exploration, industrial and metallic minerals, national mining policy, and strategic minerals identification
Local Authorities	Occasionally involved in exploration, evaluation, development, production of raw materials by designation from regions
Regional Authorities	Collects raw material data; administers minerals, thermal waters, quarries, and peat bogs. Manages solid minerals extraction. Implements regional plan for extractive activities

Fig. 2 Roles and responsibilities in Italian primary raw materials data collection and management

Table 1 Summary of measures introduced by Decree-Law No. 84 of 25 June 2024

Article	Decision/Strategy	Points of Contact	Action Plan	Relevance to CRMA	UNFC relevant
Art. 8 – Production Royalties	Introduces a production royalty (5–7%) for strategic mining concessions. Funds go to the state (offshore projects) or state & region (onshore projects).	Ministry of Economy and Finance, Ministry of Environment and Energy Security, Ministry of Industry and Made in Italy	Implement via a decree in coordination with the Unified Conference. Allocate funds to the National Made in Italy Fund for strategic raw materials investment.	Support to strategic projects funding (*CRMA* Sect. 2*)*	Unrelated
Art. 9 – Mineral Recovery from Waste	Extends existing mining regulations to allow extraction from closed/abandoned waste storage sites.	Ministry of Environment and Energy Security, Ministry of Industry and Made in Italy	Define eligibility criteria for waste extraction projects. Grant extraction permits under the extended mining law framework.	Promote secondary CRMs supply (*CRMA*, *Article 27)*	Yes
Art. 10 – National Exploration Program	Assigns ISPRA (Italian Geological Survey) responsibility for drafting the National Exploration Program.	ISPRA, Ministry of Industry and Made in Italy, Ministry of Environment and Energy Security	Establish a formal agreement between ISPRA and relevant ministries. Develop and implement the exploration program.	Expanding CRMs knowledge (*CRMA*, *Article 19*)	Yes
Art. 11 – Strategic Value Chains Monitoring	Requires monitoring of strategic value chains and national needs. Establishes a National Register of Strategic Companies & Value Chains.	Ministry of Industry and Made in Italy	Set up the registry and conduct stress tests to assess vulnerabilities in supply chains.	Supply chain resilience (*CRMA*, *Article 20)*	Yes
Art. 12 – Fast-Track Disputes on Strategic Projects	Applies fast-track legal procedures for disputes over strategic project approvals.	Ministry of Justice, Ministry of Industry and Made in Italy	Align procedures with those used for PNRR-funded projects to accelerate legal resolution.	Accelerating permitting (*CRMA*, *Article 11*)	Unrelated
Art. 13 – Support for Critical Raw Materials Processing & Extraction	Expands the National Made in Italy Fund to include extraction & processing projects. Allows INVIMIT S.p.A. to create investment funds for strategic companies' infrastructure.	Ministry of Industry and Made in Italy, INVIMIT S.p.A.	Amend fund regulations. Identify eligible projects and investment opportunities.	Fostering domestic production (*CRMA* Sect. 2)	Unrelated
Art. 14 – Export Controls on Critical Raw Materials	Strengthens export notification requirements for critical raw materials, including scrap metals. Establishes a monitoring committee.	Ministry of Industry and Made in Italy, Ministry of Foreign Affairs	Update regulations to include EU tariff codes. Monitor and evaluate market impacts.	Export Monitoring (*CRMA*, *Article 36*)	Unrelated
Art. 15 – Coordination of Sectoral Policies	Adjusts the role of the Interministerial Committee for Ecological Transition (CITE).	CITE, Ministry of Industry and Made in Italy	Align CITE's functions with new industrial policies.	Coordination and Governance (*CRMA*, *Chap. 6*)	Unrelated
Art. 16 – Strategic Companies Oversight	Modifies rules on transactions involving strategic companies.	Ministry of Industry and Made in Italy	Implement regulatory adjustments for foreign and domestic investments.	Security of Supply (*CRMA*, Sect. 2)	Unrelated
Art. 17 – Decree Implementation	Establishes decree enforcement timeline.	Government of Italy	Publish and execute the decree following parliamentary approval.	Implementation and enactment (*CRMA*, *Article 49*)	Unrelated
Motivation & Urgency	Ensures secure supply of critical raw materials and strengthens supply chains. Recognizes strategic projects as being of high public interest.	Government of Italy, Parliament	Fast-track legislative approval. Align policies with EU strategies.	National compliance with CRMA	Unrelated
Legislative Competence	Confirms state authority over competition and environmental protection. Notes regional role in mining sector.	Constitutional Court, Ministry of Industry and Made in Italy, Regional Authorities	Ensure compliance with national and EU laws. Address potential regional concerns.	National compliance with CRMA	Unrelated

variable data availability render classification a probabilistic and often imperfect, but an indispensable tool for effective decision-making (UNECE 2020). Uncertainty in resource classification stems from various matters to which knowledge may be inadequate (Speirs et al. 2015).

UNFC is a classification tool, applicable to raw material projects, based on three criteria, each represented by an axis:

- E axis (Environmental-Socio-Economic Viability): Underlines the project's alignment with environmental

impacts, social prosperity and acceptance, economic viability, and related regulations.
- F axis (Technical Feasibility): Evaluates the technical maturity and feasibility of the project.
- G axis (Geological Knowledge): Indicates the level of confidence in product estimates.

As displayed in Fig. 3, the classification of projects in UNFC is plotted on a three-dimensional scheme using a numerical coding system, that determine a *Class* (e.g., Viable, Potentially viable, Non-viable, Prospective) and *Sub-class* (e.g., On Production). Each axis is categorized from 1 to 3 (or 4 for the F and G axes), with 1 being the highest level of viability, feasibility, and confidence, and 3 (or 4) the lowest. The entire system is thus further defined with Categories and Sub-categories for each of the axes for a granular and comprehensive framework.

Table 2 illustrates a 2D plot of the UNFC cube, where most common Classes and Sub-classes are defined by the corresponding Categories and Sub-categories. As per the methodology proposed for this preliminary UNFC-based raw materials inventory for Italy, the classification of raw materials projects halted at category level, for simplification purposes and to minimize subjectivity. This means that projects were classified as Viable, Potentially Viable, Non-Viable, or Prospective Projects. Further granularity from Sub-classes and Sub-categories should be included in future updates. The definitions for each Category and Sub-category are well explained in the UNFC (2019) generic document (UNECE 2020). The viability of a project is generally determined by the E, F, and G (rarely, when it's G3 or G4) axes. However, in this study, a balanced judgement approach was taken for the viability, dominated by the E axis i.e., E1 for Viable, E2 for Potentially Viable, and E3 for Non-Viable and Prospective Projects.

In many cases, the obstacles to advancing mineral projects are not geological, but social, environmental, or economic. UNFC accounts for these dimensions through its E axis, the environmental-socio-economic viability. The E axis limitations are becoming particularly prevalent across the EU, where local acceptance, regulatory complexity, land use conflicts, and biodiversity concerns directly shape the viability of raw materials projects. At the same time, addressing the mounting supply pressures, particularly for CRMs, requires a forward-looking approach. It is therefore vital that EU Member States, including Italy, assess whether public funding should be more proactively directed toward exploration and geoscientific research. Studies consistently show that private sector exploration expenditures in Europe are insufficient relative to the projected demand (European Commission 2020).

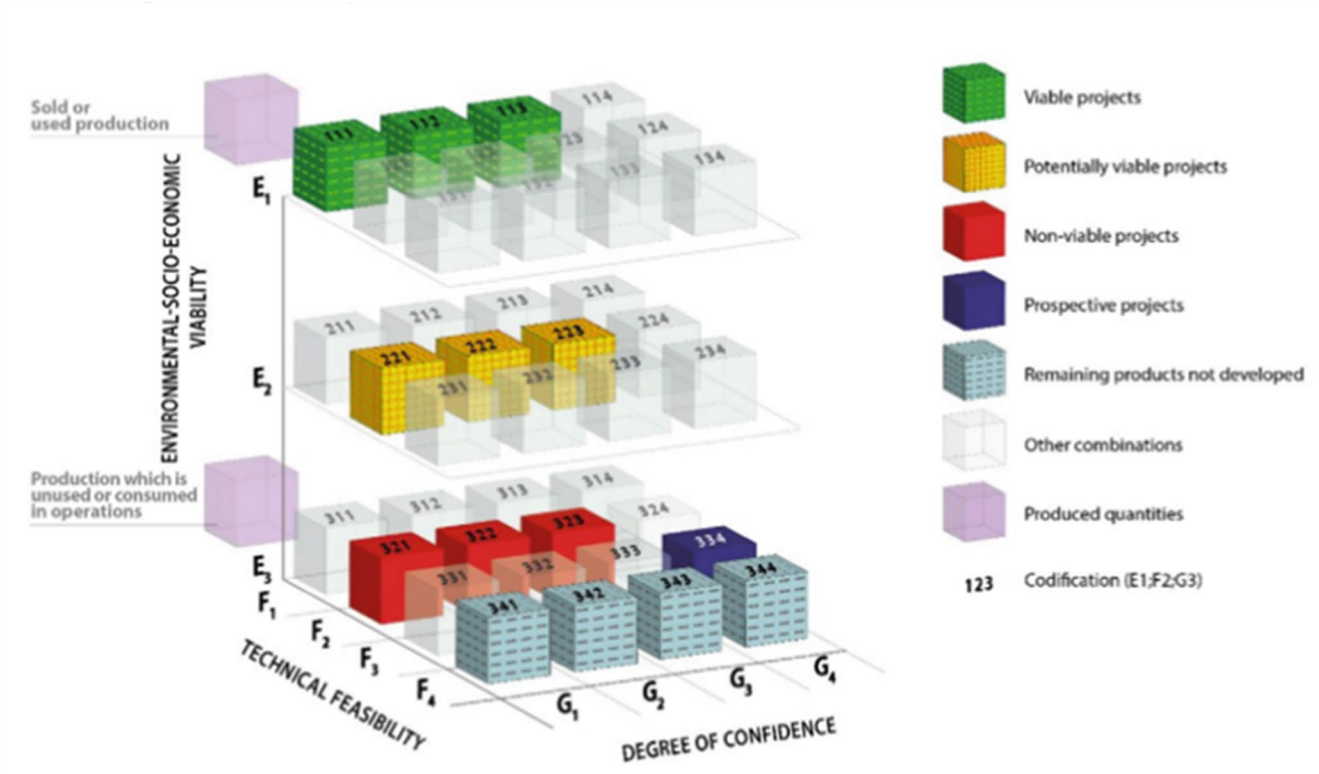


Fig. 3 A three-dimensional diagram illustrating the E, F, and G axes of UNFC, with the corresponding categories and example classes (UNECE 2020)

Table 2 The relationship between UNFC classes and Sub-classes defined by their corresponding categories and Sub-categories (UNECE 2020)

Total Products	Class		Sub-class	Categories		
				E	F	G
	Known Sources	Viable Projects	On Production	1	1.1	1, 2, 3
			Approved for Development	1	1.2	1, 2, 3
			Justified for Development	1	1.3	1, 2, 3
		Potentially Viable Projects	Development Pending	2	2.1	1, 2, 3
			Development on Hold	2	2.2	1, 2, 3
		Non-Viable Projects	Development Unclarified	3.2	2.2	1, 2, 3
			Development Not Viable	3.3	2.3	1, 2, 3
	Potential Sources	Prospective Projects	No sub-classes defined	3.2	3	4

Application of UNFC to the Italian raw materials inventory

This initial contribution for a UNFC-based Italian raw materials inventory is built on various data types and sources, was conducted independently, and is therefore intended as a methodological demonstration. Ideally, cooperation with governmental authorities and the extractive industry is warranted for supplying and validating the data inserted in the inventory. Each type of data considered a unique method of acquisition and classification, since the collation of raw materials in Italy is widely scattered and challenging (as seen in Fig. 2). The data included in the inventory are supplied from:

(i) formal reports submitted to authorities and/or public company reports on production, including raw materials projects with statutory claims (either for exploration or extraction);
(ii) historical data previously reported and/or thoroughly studied for research purposes; and.
(iii) data extrapolated from known geological occurrences and deduced from public information and/or academic reports.

Authorized raw materials projects and production data

Firstly, one way to understand and monitor Italy's raw materials potential is through the analysis of mining concessions, exploration permits granted or under review, concessions currently in force, and active production projects. Figure 4, showcasing records on exploration and mining permits as compiled by ISPRA, provided an important foundation for this understanding (Fumanti 2023). In parallel, international datasets such as the S&P Global Metals and Mining Database offered complementary insights into exploration trends and Italy's relative position in terms of resource attractiveness and project pipeline. These datasets were used in combination to build the current preliminary UNFC-based raw materials inventory (S&P Capital IQ 2025). The projects listed in Fig. 4 have been classified in accordance with their technical study phase, which in return is an indication of the permitting status. Projects yet at research phase have been assigned E3 and F3, since the environmental-socio-economic viability is at an early stage to be evaluated, and the technical feasibility at research levels. Separately, projects at exploration and pre-feasibility have been classified under the E2 and F2 categories, since they are permitted, furthering the technical feasibility, and possibly progressing towards viability.

Subsequently, data on raw materials production represented one of the most direct indicators of a country's raw material output and, by extension, its resource security, industrial demand, and economic positioning in CRMs markets. For Italy, production data were compiled from various sources such as the United States Geological Survey (USGS) Minerals Yearbook (2023), Raw Materials Information System (RMIS) and ISTAT's data portal. These datasets offered the insights included in the inventory on quantities and types of raw materials extracted domestically (USGS 2023a; USGS 2023b; RMIS 2025; ISTAT 2025). The data collected on production pertain solely to extraction projects. Ideally, a comprehensive national raw materials inventory should also include data from processing and recycling projects.

Within the UNFC framework, projects with exploration or mining titles and production data, especially when sourced from the extractive industry, are among the most straightforward to classify due to the pre-existence of established technical and commercial standards, such as those of the CRIRSCO template. When available, the CRIRSCO-reported data were added to the inventory by means of translation to UNFC, through the use of the CRIRSCO-UNFC bridging document (UNECE 2025). While it is allowed to aggregate numbers on the G axis of UNFC (as to reflect a range of uncertainty), such data were reported as aggregated figures within the preliminary inventory. For this study, the industry-reported data have been assigned to UNFC categories 1 or 2 on the G axis, with E1; F1 categories, corroborated by the fulfillment of regulatory requirements in Italy. This entails compliance with Italian mining and environmental legislations, including the Presidential

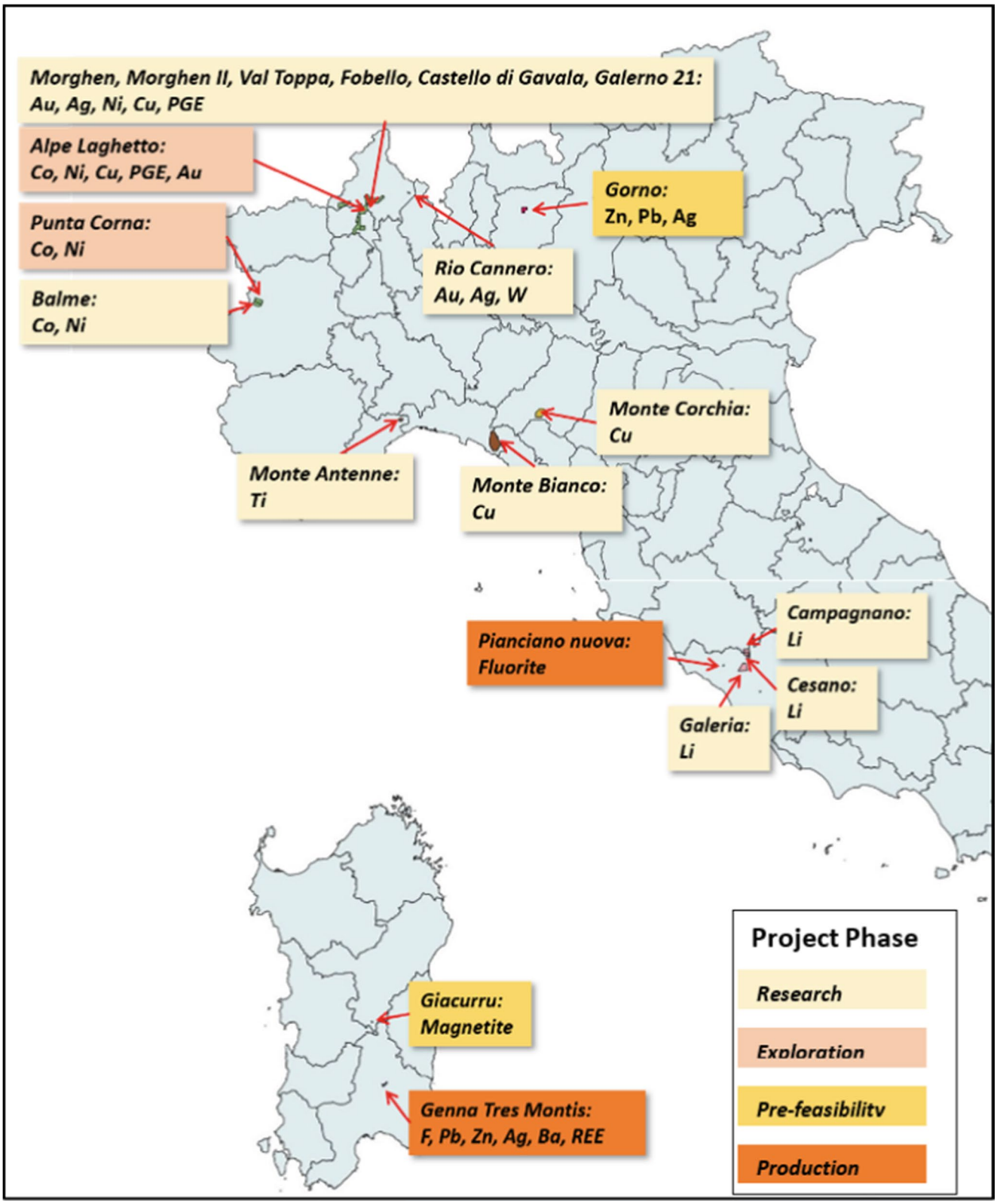


Fig. 4 Mining titles for metal ores and other CRMs, with project progress status (Fumanti 2023) – (F = Fluorspar)

Decree 128/59 (rules for mining and quarrying), Legislative Decree 152/06 (legislative framework applicable to all matters concerning environmental protection), the Law of 23 December 2000 no. 388, Art. 114 (necessitates a special plan for remediation and environmental recovery of mines), Legislative Decree no. 624/1996 (health and safety of workers), and Legislative Decree no. 117/08 (transposing Directive 2006/21/EC and important for the management of extractive waste). Collectively, compliance with these regulations supports classification under E1, reflecting strong environmental-socio-economic viability (UNECE 2022).

As an elaboration on the method of classification of data from such projects, the Gorno project (located in northern Italy, see Fig. 4) is used to make the point. Gorno is currently in an advanced exploration phase and has undergone extensive drilling and geological assessment since 2015 (Altamin Limited 2023). A publicly available JORC-compliant mineral resource estimate identifies 7.79 million tonnes of *Indicated* and *Inferred resources*, grading 6.8% Zn, 1.8% Pb, and 32 g/t Ag, as a result of the scoping study conducted in 2021 (S&P Capital IQ 2025). In line with the CRIRSCO–UNFC bridging document (UNECE 2025), these *Indicated* and *Inferred resources* were respectively classified as E2; F2; G2 and E2; F2; G3. For a direct application of UNFC to Gorno, the project complies with regulatory processes, as current activities are conducted under a granted exploration license, valid until July 2025, in addition to progression in feasibility-development and compliance with international techno-economic studies (Altamin Limited 2023). These support an E2 and F2 classification, similarly to from the bridging method.

Historical data and legacy records

Historic data on raw materials may provide insights into potential future supplies, but they are largely in-homogeneous. Therefore, UNFC is applied to historical data firstly to classify them in a harmonized manner, and secondly to understand their viability and maturity status, and subsequently their potential for recovery. Historical data were derived from the Minerals4EU (2019) project and repository held by ISPRA, regional mining authorities, and academic institutions (EGDI 2025)). These data include information on past exploration results, resource and reserve estimates (including non-compliant with industry standards or poorly documented in most cases), and deposits that are currently uneconomic. Despite their dated nature, historic estimates were included in the inventory due to their strategic importance, as they offer a broader understanding of the national raw materials base and highlight areas where future exploration may be warranted, particularly under evolving market or technological conditions (Bide et al. 2022).

Classifying historic data under UNFC is complex due to uncertainty across all three axes. In this study, these data have been classified, in most cases, under the categories E3; F3; G3, to reflect the low confidence in environmental-socio-economic viability, technical feasibility, and product quantity/quality. For these data, E3 has been predominantly assigned, since sustainability performance cannot be determined at present times due to insufficient information, or no reasonable prospects exist. Regarding the technical feasibility, F3 has been assigned due to obsolete or limited available data to determine the technical maturity, and F4 where no development has been identified. In some cases, G2 has been applied when volumes and quantities were estimated as well documented reserves, as a result of previous exploration activities i.e., where drilling and/or advanced geological investigations were conducted. As such, historical resource and reserve estimates compliant with industry standards have been assigned higher confidence categories of the G axis, in correspondence with the bridging mechanism (if existing, and if not, lower categories have been assigned). G4 has been used in instances of insufficient and indirect geological evidence. Although these data are classified as "Non-Viable" under current conditions, they remain strategically important for long-term planning. Their inclusion provides a broader perspective on the national raw materials base and may guide future exploration under changing economic, policy, or technological conditions.

For instance, as recorded by the Minerals4EU repository, a lead reserve of 4 million tonnes (2013) has been assigned a E3; F3; G2 classification, to reflect moderate geological confidence (EGDI 2025). Additionally, feldspar resource estimate of 5 million tonnes (2013), poorly documented and lacking technical validation, has been assigned E3; F4; G4. Similarly, a fluorspar resource of 35 million tonnes (2019), based on historic resource estimates without alignment to reporting standards, has been classified as E3; F3; G3. The difference in the G axis classifications between these historic estimates lies in the availability and quality of documented geological evidence, as well as the extent of investigation carried out to support the estimation (i.e., G2 if well documented reserve, G3 if well documented resource, and G4 if poorly documented resource).

Extrapolated data from geological occurrences

The attempt to build this preliminary Italian raw materials inventory also incorporates raw materials data derived from geological occurrences across the country. This approach was necessary because of the existing information gaps on raw materials and the scattered data collection streams in Italy (as demonstrated in Fig. 2). Limitations arose on this particular data source, namely from occurrences that are not

publicly reported, either due to confidentiality matters or the absence of legal reporting obligations from private companies. Data on geologic occurrences were sourced from a variety of publicly available materials, mainly inferred from geological mapping, geological survey reports, academic research publications, regional assessments, and government publications. It is to be noted that in this attempt, the extrapolation of such data has been carried out at regional, and in some cases, at national levels. However, Fig. 5, developed by the Italian geological survey, represents a good starting point for harnessing information on CRMs occurrences in Italy (Fumanti 2023). Incorporating such data in this study relied on published and public information on occurrences type, mineralized zones, and associated volumes or grades. Where available, these data were cross-checked with historical records and mineralogical studies to increase reliability i.e., mainly qualitatively. Quantitative estimates for these occurrences, such as in-situ tonnages, grade ranges, and spatial distribution, were reviewed. Although this method did not involve a full geospatial analysis using GIS, as used in other countries like the United Kingdom (Bide et al. 2022), it adopted a similar logic of inference by interpreting geological mapping, large-scale models, and documented occurrences to approximate potential volumes. Ideally, this exercise should be conducted on the scale of individual occurrences.

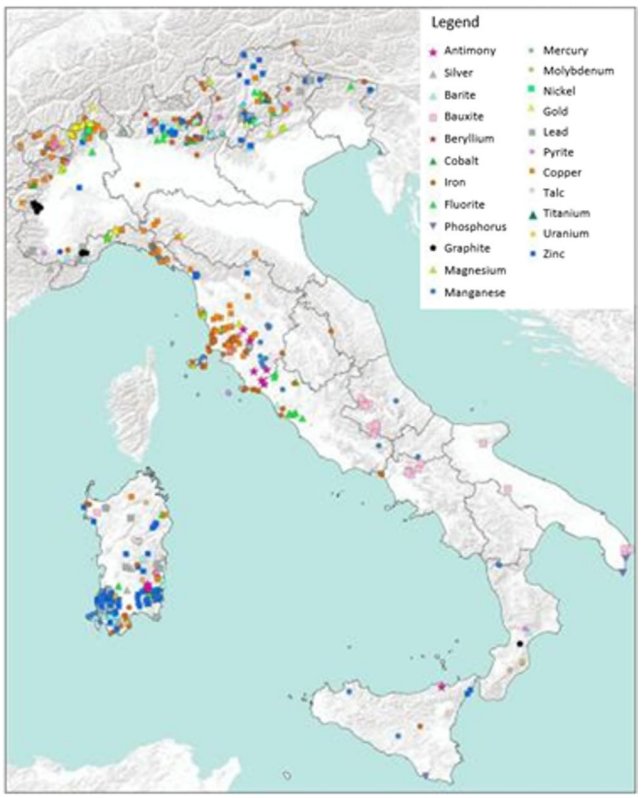
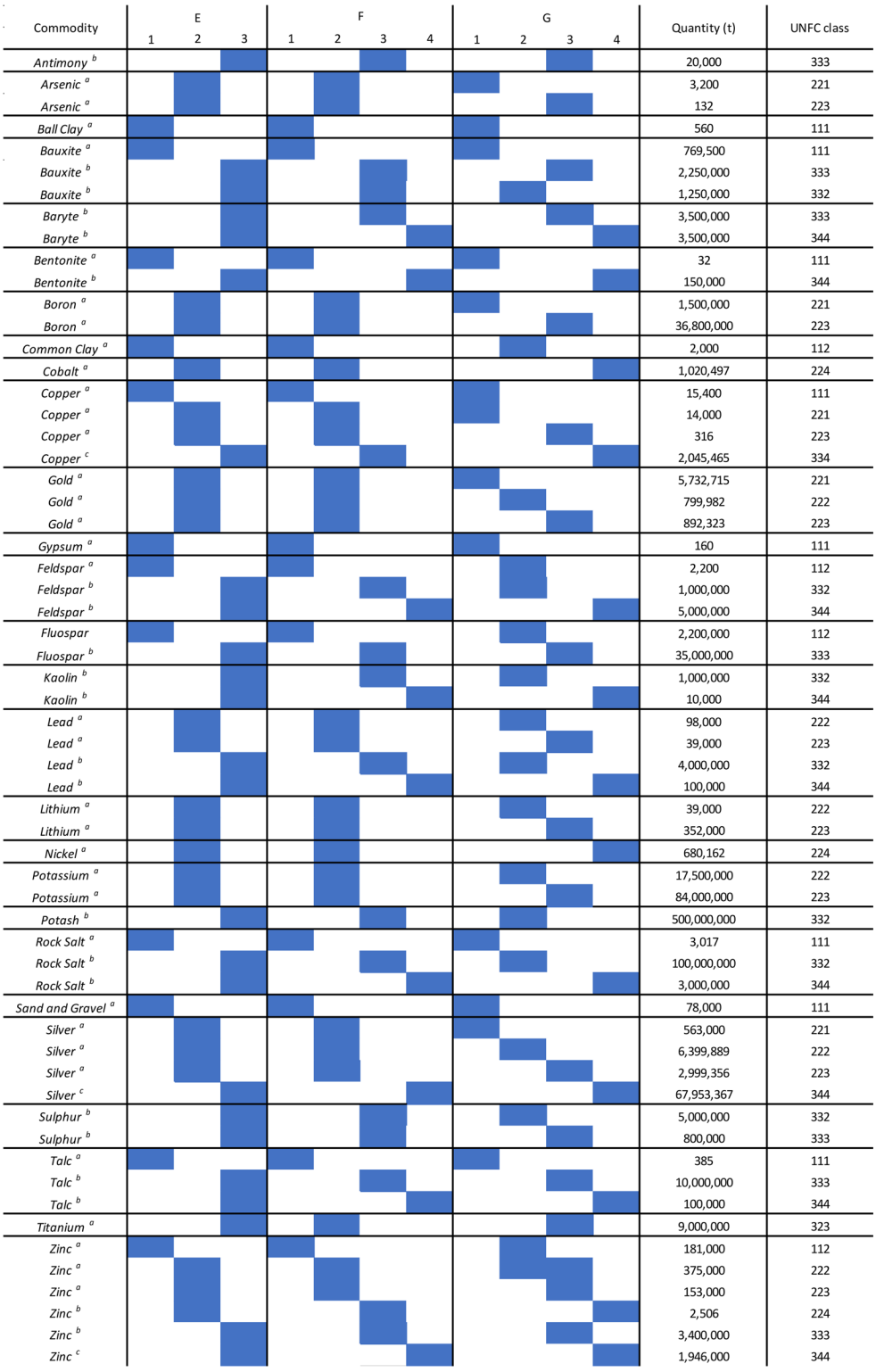


Fig. 5 Occurrences of CRMs and other metal minerals (Fumanti 2023)

Applying UNFC to these data reflects the low confidence and lack of credible sources across the E, F, and G axes. Thus, these data have been classified under E3; F3; G4 or E3; F4; G4 categories. Since these occurrences have no plausible indications on the environmental-socio-economic viability in regards to future conditions, they have been classified as E3. Regarding the technical feasibility, a distinction has been made between 'F3' and 'F4' based on the presence and maturity of the occurrence development. For regional or occurrence-based studies with no deposit-specific information, F4 classification has been assigned. On the other hand, the distinction between G3 and G4 depended on whether estimations were carried primarily on direct (G3) or indirect (G4) evidence. The low categorization indicates the raw nature of these data, which are either at initial stage or not the subject of systematic exploration or feasibility studies. It is to be noted that the use of such data in the inventory is intended to showcase the potential of raw materials in Italy, including those occurrences that have not yet been fully characterized or developed. Future iterations of the inventory should aim to improve the confidence of this data type through systematic national-scale surveys, deposit-specific assessments, and resource and reserve estimation.

Results of a preliminary UNFC-based Italian raw materials inventory

Our contribution for this first-of-its-kind attempt of an Italian national raw material inventory is provided in Fig. 6. It presents the classification of Italian raw material commodities, gathered from the aforementioned data sources and acquisition methodologies (Sect. 3), according to UNFC. The data source used for each commodity is indicated by the superscripts: "a" from projects and production data, "b" from historical data, and "c" from occurrences. The inventory is mainly populated by data from reported mining projects and production ("a"), followed by legacy records ("b"). By contrast, extrapolated geological occurrences ("c") are only sparsely represented, as they lack robust information on quantities and quality. Quantities for each commodity, expressed in metric tonnes, are estimated and classified across the corresponding E, F, and G axes. The full dataset for the development of the inventory, the projects and their sources, collation and classification is available as supplementary information. The development of this inventory is inspired by the UK minerals inventory in UNFC (Bide et al. 2022). Similarly, each cell has been shaded based on its assigned UNFC category for each axis, as a visual summary of the UNFC axes in a two-dimensional layout. This approach illustrates, for each commodity, a progression from higher to lower confidence levels, moving diagonally



Commodity	E			F				G				Quantity (t)	UNFC class
	1	2	3	1	2	3	4	1	2	3	4		
Antimony [b]												20,000	333
Arsenic [a]												3,200	221
Arsenic [a]												132	223
Ball Clay [a]												560	111
Bauxite [a]												769,500	111
Bauxite [b]												2,250,000	333
Bauxite [b]												1,250,000	332
Baryte [b]												3,500,000	333
Baryte [b]												3,500,000	344
Bentonite [a]												32	111
Bentonite [b]												150,000	344
Boron [a]												1,500,000	221
Boron [a]												36,800,000	223
Common Clay [a]												2,000	112
Cobalt [a]												1,020,497	224
Copper [a]												15,400	111
Copper [a]												14,000	221
Copper [a]												316	223
Copper [c]												2,045,465	334
Gold [a]												5,732,715	221
Gold [a]												799,982	222
Gold [a]												892,323	223
Gypsum [a]												160	111
Feldspar [a]												2,200	112
Feldspar [b]												1,000,000	332
Feldspar [b]												5,000,000	344
Fluospar												2,200,000	112
Fluospar [b]												35,000,000	333
Kaolin [b]												1,000,000	332
Kaolin [b]												10,000	344
Lead [a]												98,000	222
Lead [a]												39,000	223
Lead [b]												4,000,000	332
Lead [b]												100,000	344
Lithium [a]												39,000	222
Lithium [a]												352,000	223
Nickel [a]												680,162	224
Potassium [a]												17,500,000	222
Potassium [a]												84,000,000	223
Potash [b]												500,000,000	332
Rock Salt [a]												3,017	111
Rock Salt [b]												100,000,000	332
Rock Salt [b]												3,000,000	344
Sand and Gravel [a]												78,000	111
Silver [a]												563,000	221
Silver [a]												6,399,889	222
Silver [a]												2,999,356	223
Silver [c]												67,953,367	344
Sulphur [b]												5,000,000	332
Sulphur [b]												800,000	333
Talc [a]												385	111
Talc [b]												10,000,000	333
Talc [b]												100,000	344
Titanium [a]												9,000,000	323
Zinc [a]												181,000	112
Zinc [a]												375,000	222
Zinc [a]												153,000	223
Zinc [b]												2,506	224
Zinc [b]												3,400,000	333
Zinc [c]												1,946,000	344

Fig. 6 Preliminary UNFC-based Italian raw materials inventory

from the top left to the bottom right of each section. Given the data limitations, this inventory aims, to the extent possible, to be as thorough as possible. The figures presented for many commodities do not capture the full extent of what may exist underground. Additional, yet-to-be-discovered deposits likely exist, but quantifying them would require further exploration efforts (Bide et al. 2022).

As a further elaboration from Fig. 6; Table 3 is an excerpt focused exclusively on CRM-related data. These have been classified into Viable Projects (111 and 112), Potentially

Table 3 UNFC-based CRMs inventory for Italy

UNFC Classification	Viable Projects		Potentially Viable Projects				Non-Viable Projects	Prospective Projects		
	111	112	221	222	223	224	323	333	334	344
Antimony								20,000		
Arsenic			3,200		132					
Bauxite	769,500							2,250,000	1,250,000	
Baryte								3,500,000	3,500,000	
Boron			1,500,000		36,800,000					
Cobalt						1,020,497				
Copper	15,400		14,000		316	2,045,465				
Feldspar		2,200						1,000,000		5,000,000
Fluorspar		2,200,000						35,000,000		
Lithium				39,000	352,000					
Nickel						680,162				
Titanium							9,000,000			
Zinc		181,000		375,000	153,000	2,506		3,400,000		1,946,000

Viable Projects (221 to 224), Non-Viable Projects (323), and Prospective Projects (333, 334, and 344). All figures are reported in metric tonnes. The distribution of CRMs across these categories reveals three notable trends. First, a substantial portion of the classified quantities lies within the "Potentially Viable" class, reflecting either technical immaturity or the need for improved environmental-socio-economic viability before development. Quantities classified under "224" pertain to unreliable estimates, deduced and roughly calculated from preliminary public sources and informal data despite being registered projects, and as such, are included only for the purpose of this inventory. Second, a smaller share of CRMs has been classified under the "Viable" category, indicating mature projects ready for or already undergoing production. It is noteworthy to mention that only Titanium has been classified under the "Non-Viable" (red) category, reported from a UNFC case study applied on the Piampaludo Titanium Exploration Project (UNECE 2023). Third, prospective projects remain abundant, and represent future potential. The quantities presented in Table 3 have been aggregated from the multiple sources, and compiled per commodity. This aggregation represents the sum of the same UNFC categories for each commodity to provide a consolidated national-level estimate per classification level.

Discussion

EU Member States are employing diverse national systems to classify and report raw material data, which leads to inconsistencies that hinder comparability and harmonized policymaking at EU scales. Over recent years, initiatives such as the ORAMA project (Optimizing Quality of Information in Raw Materials Data Collection across Europe) have demonstrated UNFC's capacity to harmonize this fragmented landscape, with a consistent classification that integrates geological, technical, and environmental-socio-economic dimensions (Bide 2018). Additionally, the European Commission has acknowledged UNFC's potential to serve as this raw materials harmonization tool, particularly in CRMA. UNFC's multidimensional structure provides a transparent, scalable, and integrative framework to support decision-making at various stages of the resource development lifecycle, from early-stage exploration to production. When applied to national inventories, UNFC transforms the concept of raw materials aggregation beyond mere geological quantification. It embeds feasibility assessments, market conditions, permitting status, and environmental and social aspects, thus allowing policymakers to make informed decisions grounded in sustainability and long-term value. Furthermore, UNFC's applicability to both primary raw materials and secondary raw materials is especially relevant for the EU, where increased attention is being given to secondary raw materials. In this context, UNFC serves as a classification tool, capable to support public authorities in policy-making, reporting, and monitoring, while also enabling companies to plan, evaluate, and communicate projects more strategically and sustainably.

The exercise presented in this paper has tested the applicability of UNFC to a national raw materials inventory for Italy and has revealed a number of methodological and operational challenges, many of which can be found elsewhere in Europe. The proposed Italian CRMs inventory aggregates a heterogeneous dataset encompassing exploration projects, active production data, historical records, academic sources, and publicly available databases. It should be noted that, while ore grade is a critical factor in determining true recoverable resources, the aggregation presented in the CRMs inventory (Table 3) does not differentiate by

grade. This is primarily due to the heterogeneity and limited availability of consistent grade data across different sources. In many cases, grades were either unreported or based on non-comparable analytical methods. As a result, aggregating quantities with different grades would overcomplicate the inventory and risk misrepresenting the purpose of this paper. Therefore, the CRMs inventory serves as generalized indicative volume estimates rather than precise recoverable resources. Where available, grade information is retained and considered in the classification process (available in supplementary information) but it is not reflected in the total aggregated quantities presented in Table 3. The diversity of sources reflects the fragmented nature of existing data infrastructures and underscores the need for a centralized, harmonized classification approach. Although the transformation of such varied inputs into a coherent and consistent UNFC-based inventory is inherently complex, the proposed methodology adopts a systematic approach for the different sources, quality of data, and levels of confidence to handle such complexity.

In the Italian case, a significant proportion of estimates originated from legacy datasets and regionally aggregated studies. As such, many records were assigned to lower-confidence categories (e.g., E3; F3; G3 or G4). It is recommended for future iterations to sub-divide the G4 categories (G4.1, G4.2, G4.3) to add more granularity unto early stage exploration classifications. Given that the data used are only from publicly available sources, it is to be noted that the presented inventory most likely underestimates the country's total subsurface potential, since restricted data kept at company or governmental level were not accessed. Besides, the upcoming Italian national exploration programme could reveal new potential. As a simplification, this study adopts a single G axis category to represent each estimate, favoring the most dominant and reliable classification rather than combining multiple G axis categories, as permitted under full UNFC methodology. The baseline inventory represents a step in building a structured and expandable raw materials knowledge system, that serves as an important policy tool for governments. The trend observed where higher confidence correlates with smaller volumes reinforces the need for caution in interpreting aggregated totals. Users must remain aware that actual extractable volumes are substantially lower than the total geological endowment (Bide 2022). This observation further strengthens the case for data validation, deposit-specific assessments, and systematic national-scale exploration campaigns to improve future inventory iterations.

At the EU scale, the integration of UNFC into Italy's national CRM inventory can contribute to the objectives of CRMA. UNFC allows for comparable data from EU Member States, which enables more accurate criticality assessments, stress-testing exercises, and policy interventions across the value chain. Implementing a UNFC-based national raw materials inventory, decision-makers can better understand where to focus attention, which policy instruments are needed, where capital should be allocated, and how to integrate environmental and social safeguards into development strategies. This supports a holistic and evidence-based method to advance mineral supply security without compromising Italy's broader commitments to environmental sustainability, economic growth, and social well-being. The proposed Italian CRMs inventory, when continuously updated, can serve as a dynamic tool for tracking progress in the raw materials sector, identifying national supply bottlenecks, and aligning national efforts with EU strategic objectives under CRMA. This kind of understanding is particularly relevant in the context of reducing Italy's dependence on external suppliers, for high-risk and economically important CRMs (Agenzia Nova 2024). Importantly, the ability to distinguish between Viable, Potentially Viable, and Prospective projects through UNFC enhances the effectiveness of CRMA requirements for reporting. Projects falling within the Potentially Viable class are particularly relevant, as they often require targeted support, financial or permitting, to progress toward production. Meanwhile, Prospective Projects can guide future exploration and policy attention. Even projects assigned to Non-Viable categories should not be disregarded; such records offer long-term strategic value, particularly when combined with technological progress and innovation, and circular economy solutions. Furthermore, UNFC elevates raw materials inventories into instruments of governance by embedding ESG considerations into resource evaluation. This also aligns with CRMA's emphasis on responsible sourcing, environmental performance, and public acceptance.

It is interesting to note that, despite its advantages, the adoption of UNFC has so far been limited. This can be attributed to the continued use of well-established national and industry-specific reporting systems (e.g., CRIRSCO codes), as well as the need for UNFC capacity building and technical expertise. However, new policy drivers such as CRMA and the African Mineral and Energy Resources Classification and Management System (AMREC) are providing momentum for broader uptake.

Conclusion

This study presents a structured attempt to incorporate UNFC on a proposed model of national raw materials inventory for Italy. The implementation of UNFC provides a multidimensional perspective supporting a robust, transparent, and harmonized classification that not only accounts

for geological potential but also incorporates environmental, social, and economic dimensions. Reliable and continually updated datasets will be essential for feeding into the UNFC-based national raw materials inventory. This preliminary inventory is also an opportunity to expand to secondary raw materials, incorporating the potential sourced from anthropogenic resources, either from mining waste or end-of-life.

The presented Italian case illustrates both the challenges and opportunities of integrating UNFC into national resource inventory that can be used for sustainable management practices. The outcome of the proposed inventory demonstrates that Italy has untapped raw materials potential that could be strategically developed to enhance supply security. Additionally, systemic barriers such as limited exploration investment, fragmented data, and socio-environmental constraints must be acknowledged and addressed through proactive planning and governance.

The development of a UNFC-based primary and secondary raw materials inventory for Italy can represent more than just a technical exercise, it can be a meaningful contribution in view of information based national resource management practices. While challenges related to data quality, classification consistency, and resource estimation persist, the methodology proposed in this paper offers a replicable and scalable approach to building information-based, raw materials governance systems. Continued collaboration with the Italian Geological Survey and relevant ministries will be essential to enhance this proposed inventory.

This study draws specific implications for different stakeholders. For the national government, a UNFC-based inventory serves as a strategic tool for long-term planning and policy formulation, as well as to address risks on supply security. For industry, UNFC enables more consistent project reporting, access to green investment, and bridge the communication with authorities and civil society, with a classification based on environmental, social, and economic dimensions. For the EU, this case demonstrates the feasibility of developing a UNFC-based inventory that can feed into EU-wide platforms (e.g., EGDI, RMIS), contributing to cross-country comparability across EU Member States, and strengthening Europe's collective capacity to secure CRMs in a sustainable manner.

Future work should prioritize three key directions: (i) expansion of the inventory to include secondary (anthropogenic) raw materials; (ii) development of standardized protocols for data acquisition, validation, and classification across regions and commodities; and (iii) integration of UNFC-based inventories with national decision-support systems and EU-wide platforms.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s13563-025-00552-4.

Acknowledgements This work has benefited from the support and collaboration of GeoSciences IR, the Geological Survey of Slovenia, and Ms. Charlotte Griffiths from UNECE for the valuable guidance and encouragement.

Author contributions Conceptualization: G.S., S.S., G.A.B.; Methodology: G.S., S.S., G.A.B.; Formal analysis and investigation: G.S.; Writing - original draft preparation: G.S.; Writing - review and editing: G.S., S.S., G.A.B.; Funding acquisition: G.A.B., S.S.; Resources: G.A.B., S.S.;Supervision: G.A.B, S.S.

Funding Open access funding provided by Politecnico di Torino within the CRUI-CARE Agreement. This work was supported by European Union - Next GenerationEU - Mission 4 "Education and Research" - Component 2 "From Research to Business" - Investment 3.1 "Fund for the realization of an integrated system of research and innovation infrastructures" - Project IR0000037 - GeoSciences IR - CUP I53C22000800006.

Data availability Data is provided within the supplementary information file.

Declarations

Competing interests The authors declare no competing interests.

References

Agenzia Nova (2024) Materie prime in Italia: dove sono e come ridurre la dipendenza dalla Cina. Agenzia Nova. https://www.agenzianova.com/en/news/materie-prime-in-italia-dove-sono-e-come-ridurre-la-dipendenza-dalla-cina/. Accessed January, 2025

Altamin Limited (2023) Annual report for the year end 30 June 2023. ASX. https://announcements.asx.com.au/asxpdf/20230929/pdf/05vhbczmqtkq44.pdf. Accessed May, 2025

Bide T et al (2018) Final analysis and recommendations for the improvement of statistical data collection methods in Europe for primary raw materials. WP1 deliverable, ORAMA Project, Grant Agreement no. 776517

Bide T et al (2022) Development of decision-making tools to create a harmonised UK national mineral resource inventory using the United Nations framework classification. Resour Policy 76:102558

European Commission (2020) Critical materials for strategic technologies and sectors in the EU - a foresight study, 2020. 10.2873/58081

European Commission (2025) Press release: Commission selects 47 strategic projects to secure and diversify access to raw materials in the EU. EU Press Corner. https://ec.europa.eu/commission/presscorner/detail/en/ip_25_864. Accessed May, 2025

European Geological Data Infrastructure (EGDI) (2025) Minerals intelligence network for Europe (Minerals4EU) project database. https://www.europe-geology.eu/data-tools/map-viewer/. Accessed May, 2025

European Union (2025) The future of European competitiveness: a competitiveness strategy for Europe. https://commission.europa.eu/document/download/97e481fd-2dc3-412d-be4c-f152a8232961_en?filename=The%20future%20of%20European%20competitiveness%20_%20A%20competitiveness%20strategy%20for%20Europe.pdf. Accessed June, 2025

European Parliament and Council of the European Union (2024) Regulation (EU) 2024/1252 of 11 April 2024 establishing a framework for ensuring a secure and sustainable supply of critical raw materials and amending regulations (EU) No 168/2013, (EU) 2018/858, (EU) 2018/1724 and (EU) 2019/1020 (Text with EEA relevance). Official Journal of the European Union, L 125/1. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L_202401252

Eurostat (2025) Structural business statistics overview – mining and quarrying. https://ec.europa.eu/eurostat/databrowser/view/sbs_sc_ovw/default/table?lang=en. Accessed April, 2025

Fumanti F (2023) Materie prime critiche/stratgiche, le attività per la definizione delle potenzialità nazionali. https://www.senato.it/application/xmanager/projects/leg19/attachments/documento_evento_procedura_commissione/files/000/427/371/2023_07_18_ISPRA.pdf

U.S. Geological Survey (2023a) Mineral commodity summaries 2023: U.S. Geological Survey (210 pp). 10.3133/mcs2023

U.S. Geological Survey (2023b) Data release for mineral commodity summaries 2023: U.S. Geological Survey data release. 10.5066/P9WCYUI6

U.S. Geological Survey (2021) Mineral commodity summaries 2021: Fig. 1. p. 4. 10.3133/mcs2021

GMK Center (2024) Italy imported 7.2 million tons of steel from third countries in 2023. https://gmk.center/en/news/italy-imported-7-2-million-tons-of-steel-from-third-countries-in-2023/. Accessed April, 2025

Grandi S (2019) Italy country report, update. MINLEX project, grant number SI 2.717317

Grohol M (2024) UNFC in the EU critical raw materials act. UNECE resource management week 2024 – UNFC seminar. https://unece.org/sites/default/files/2024-04/10.%20Milan%20Grohol.pdf. Accessed May, 2025

IEA (2021) Net Zero by 2050, IEA, Paris https://www.iea.org/reports/net-zero-by-2050, Licence: CC BY 4.0

IEA (2025) Global critical minerals outlook 2025, IEA, Paris https://www.iea.org/reports/global-critical-minerals-outlook-2025, Licence: CC BY 4.0

ISPRA (2012) Geological Map at a scale 1: 50 000 (CARG Project) [Interactive map]. Istituto Superiore per la Protezione e la Ricerca Ambientale, from https://www.isprambiente.gov.it/Media/carg/index.html. Accessed June, 2025

ISPRA (2025) Piano nazionale energia–clima: documento finale. https://www.isprambiente.gov.it/files2025/attivita/pne_finale.pdf. Accessed July, 2025

Italian National Institute of Statistics (2025) Mining and quarrying sector data. https://esploradati.istat.it/databrowser/#/en/dw/categories/IT1,Z0920ENV,1.0/DCCV_CAVE_MIN/IT1,9_951_DF_DCCV_CAVE_MIN_2,1.0. Accessed April, 2025

Marllat J (2020) The role of industry–academia collaborative research in mineral exploration. Can Miner 59(5). 10.3749/canmin.1900086

Marmomacchine International (2024) Nel 2023 lieve flessione per l'export italiano di pietre naturali [Slight decline in Italian natural stone exports in 2023]. https://www.marmomacchineinternational.com/en/nel-2023-lieve-flessione-per-lexport-italiano-di-pietre-naturali/. Accessed April, 2025

McKelvey VE (1972) Mineral resource estimates and public policy. Am Scientist 60(1):32–40

Naegler T et al (2025) Raw material demand and geopolitical risk in carbon-neutral futures. Energy Policy. https://doi.org/10.1016/j.enpol.2025.114622

Parker D et al (2015) Minventory: EU raw materials statistics on resources and reserves. EC-11 331 minventory final report. https://rmis.jrc.ec.europa.eu/uploads/EC-11_331_Minventory_Final_Report.pdf

Raw Materials Information System (RMIS) (2025) Platform. Country Profile: Italy. Accessed May, 2025

Reuters (2024) Italy revises down 2023 GDP growth, budget deficit, debt. https://www.reuters.com/markets/europe/italy-revises-down-2023-gdp-growth-budget-deficit-debt-2024-09-23/

S&P Capital IQ Capital IQ (2025) Platform. S&P Global Market Intelligence. https://www.capitaliq.spglobal.com/. Accessed May, 2025

Senato della Repubblica (2024) Disposizioni urgenti sulle materie prime critiche di interesse strategico. D.L. 84/2024 – A.C. 1930. Dossier n. 305. Servizio Geologico d'Italia, 1973. Carta Mineraria d'Italia, scala 1:1.000.000 (Mining Map of Italy, 1:1.000.000 scale). Litografia Artistica Cartografica, Firenze

Speirs J, Laister S, Gross R et al (2015) Uncertainty in the availability of natural resources: fossil fuels, critical metals and biomass. Energy Policy 87:654–664

Statista (2025) Imports and exports of stone and mineral construction materials in Italy. https://www.statista.com/statistics/1417949/imports-and-exports-of-stone-and-mineral-construction-materials-italy/. Accessed April, 2025

Trading Economics (2025) Italy exports of non-metallic mineral processed products. https://tradingeconomics.com/italy/exports-of-non-metallic-mineral-processed-products. Accessed April, 2025

UNECE (2020) United nations framework classification for resources (UNFC 2019). United Nations economic commission for Europe. https://unece.org/sites/default/files/2023-10/UNFC_ES61_Update_2019.pdf

UNECE (2022) UNFC guidance Europe: guidance for the application of the United Nations framework classification for resources (UNFC) for mineral and anthropogenic resources in Europe. https://unece.org/sites/default/files/2022-10/Revised_UNFC_Guidance_Europe_as_of_19.October.2022.pdf

UNECE (2023) Titanium UNFC case study. https://unece.org/sites/default/files/2023-05/Titanium%20UNFC%20Case%20Study_ECE_ENERGY_GE.3_2023_7_www.pdf

UNECE (2025) Bridging document between the committee for mineral reserves international reporting standards template and the United nations framework classification for resources (2025). https://unece.org/sites/default/files/2025-01/ECE_ENERGY_GE.3_2025_6_CT%20UNFC%20BD_EN_0.pdf

Wittenberg A et al (2024) Europe's raw materials supply chain: front-end considerations

World Bank (2021) Accelerating sustainable finance together. Global progress report of the sustainable banking and finance network. Evidence of policy innovations and market actions across 43 emerging markets. https://documents1.worldbank.org/curated/en/099090408092232502/pdf/IDU02de5d2a60a21304193095ad06e77a84529b5.pdf