The Italian Database GeMMA: from monitoring production to cataloguing mining wastes, a starting point for recovering critical raw materials from abandoned mines?

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The Geological Survey of Italy (ISPRA) is developing the GeMMA geodatabase by collecting all relevant information (e.g. activities, resources/reserves, production figures, and mining wastes) on Italian extractive sites from available sources. Attention is also given to extractive waste from closed or abandoned storage facilities – usually heaps or ponds – that can contain recoverable raw materials. The main purpose of the database is to define the situation of both active and historical extractive resources from mines and quarries, including geological, environmental, cultural and economic aspects. GeMMA aims to become a valid tool for developing national and regional policies oriented towards the sustainable mining/quarrying of primary mineral resources, in a circular economy perspective, considering also the exploitation potential of any secondary resources produced.

Le Département des Etudes Géologiques d'Italie (ISPRA) développe la Base de données GeMMA en recueillant des informations pertinentes (activités concernant les ressources et réserves minières, les volumes de production et les déchets miniers) provenant des données disponibles pour les gisements italiens en exploitation. Une attention particulière est prêtée également aux déchets d'exploitation stockés en des lieux confinés ou abandonnés – habituellement sous forme de terrils ou en bassins – qui peuvent renfermer des matières premières récupérables. L'objectif principal de cette Base de données est de préciser la situation des ressources d'exploitation, à la fois actuelles et anciennes, produites par les gisements miniers ou les carrières, en incluant les volets géologique, environnemental, culturel et économique. L'objectif de GeMMA est de devenir un outil reconnu pour le développement des politiques nationales et régionales orientées vers les ressources minérales primaires, renouvelables, extraites de gites miniers et de carrières, dans le cadre d'une économie circulaire, en tenant compte aussi de l'exploitation potentielle de toutes les ressources secondaires produites.

El Servicio Geológico de Italia (ISPRA) está desarrollando la base de datos geológicos GeMMA mediante la recopilación de toda la información relevante (por ejemplo, actividades, recursos / reservas, cifras de producción y desechos mineros) en sitios de extracción italianos provenientes de fuentes disponibles. También se presta atención a los desechos extractivos de instalaciones de almacenamiento cerradas o abandonadas, generalmente rellenos o balsas, que pueden contener materias primas recuperables. El objetivo principal de la base de datos es definir la situación de los recursos extractivos activos e históricos de las minas y canteras, incluidos los aspectos geológicos, ambientales, culturales y económicos. GeMMA apunta a convertirse en una herramienta válida para desarrollar políticas nacionales y regionales orientadas hacia la extracción minera sostenible de recursos minerales primarios, en una perspectiva de economía circular, considerando también el potencial de explotación de cualquier recurso secundario producido.

Raw materials in Italy: a general overview

The production and supply of mineral raw materials from mines and quarries are of strategic importance for the economy, both for the European Union and on a national scale. Although the EU has an important role in the world production of construction minerals and industrial minerals, for many raw materials, whose demand is continuously increasing, the European industry remains heavily dependent on imports, even from countries where mining/sourcing is not always taking place responsibly and sustainability is often poorly addressed. Europe, including Italy, therefore needs to better manage its untapped mineral resources, including the implementation of more efficient recovery and recycling strategies. In this sense, we are moving towards addressing the challenging opportunity of combining the economic competitiveness of production with a socially acceptable impact on the environment through "sustainable mining" (Carvalho, 2017; Careddu *et al.*, 2018).

In Italy, despite the obvious decrease in production recorded since 2008, the extractive industry of non-energy mineral resources remains an important economic sector (***Figure 1***), in particular for industrial and construction minerals. Thus, at national level, Italy should take on the task of launching a shared strategy between the state and the regions, in compliance with their respective skills, which can maintain and strengthen the competitiveness of country's mining industry with a view to sustainable management and development, based on resource-efficient value chains and related increased reuse and recycling capacity.

Figure 1: Active quarry in the Apuan Alps (Carrara Marble District, Tuscany).

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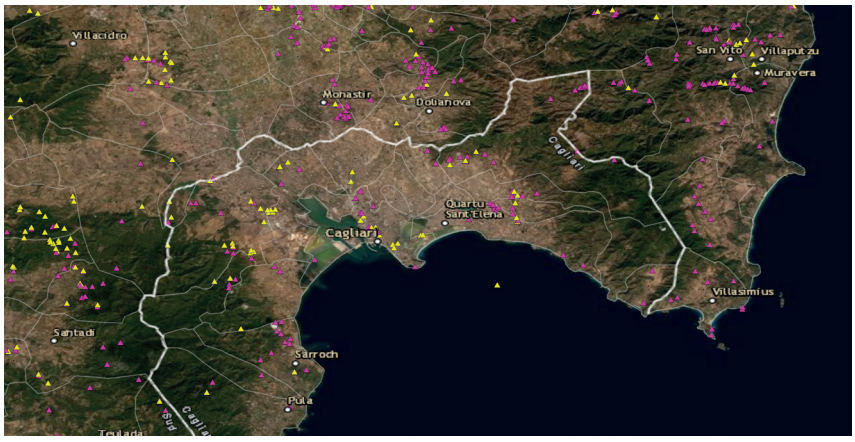

Figure 2: Output of the preliminary GeMMA geodatabase showing the closed and active mining sites for non-energy minerals in the southern Sardinia. Since information is derived from different databases, a cross-check of the site location was performed. The verified and harmonized sites have been reported in violet, the undefined and not still verified sites are in yellow. The off-shore site is a marine sand extractive site for beach nourishment.

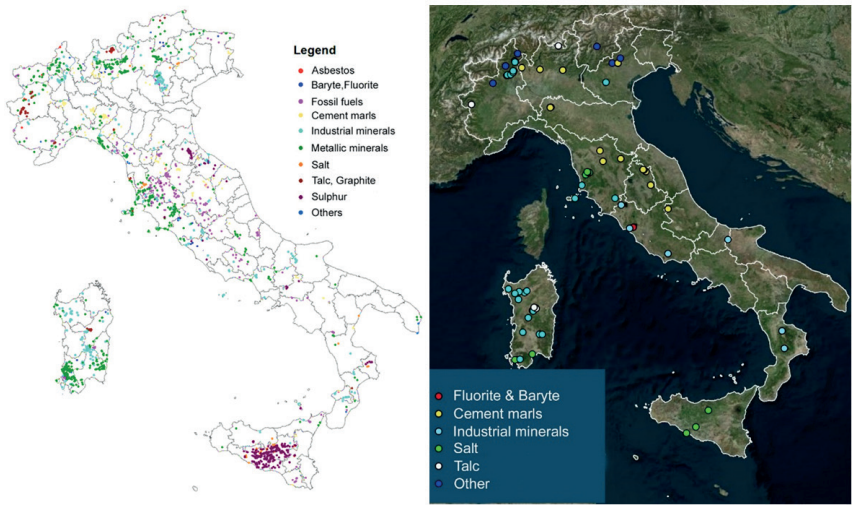

Figure 3: Distribution of mines operating between 1870 and 2018 (left), and current mining concessions (right).

Table 1: Mines production (tons) in Italy between 2015 and 2017.

	2015	2016	2017
Cement marls	5185	5537	5980
Industrial minerals (Kaolin, Feldspar, Bentonite, Clays)	5223	5703	6186
Salt	2081	2085	2147
Others (Talc, Baryte, Fluorite, Olivine, Magnesium salts)	1490	345	510
TOTAL production (t*1000)	**13980**	**13671**	**14823**

Legislative framework in Italy

The mining legislation in Italy still dates back to Royal Decree No. 1443/1927, which distinguishes the extractive industries of strategic minerals (first category, mines) and those of minerals with less economic impact (second category, quarries and peat bogs). The mines are state-owned and subject to a concession procedure, while the quarries fall under private law and are subject to an authorization procedure (Carta *et al.*, 2017a).

Nowadays the administrative and technical skills relating to the extraction of non-energy minerals have been transferred, at different times, to the regions (quarries: Presidential Decree 24 July 1977 No. 616; mines: Legislative Decree March 31, 1998 No. 112 and Legislative Decree June 22, 2012 No. 83); in addition, at different times, all regions have legislated on the matter. The absence of national guidelines has generated diversified regional planning and heterogeneous databases in terms of data quality and data completeness. This situation requires the collection and harmonisation of the available data and their organisation in a dedicated IT structure to obtain an organic framework at national level. Italy is one of the few European countries that still does not have a national inventory of ceased, active and operating not-energy mining activities.

The mineral resources database of Italy (GeMMA)

Taking into account the Italian mineral data fragmentation, the Geological Survey of Italy (ISPRA) is building a *Geological, Mining, Museum and Environmental Database* (***Figure 2***) to collect all relevant information from national and regional/provincial public and private sources. Based on the Minerals4EU Project (refinanced in 2018 through GEOERA by the Mintell4EU Project, which ISPRA is a partner of) the PostgreSQL database is being designed with an INSPIRE-compliant architecture and contains the geographic and documentary information of mining sites (quarries and mines: active, closed or abandoned and restored) of the entire Italian territory (Carta *et al.*, 2017b). It responds to the need to harmonise information with the participation and sharing of the regions through shared projects.

The main purpose is to define the national situation of mining and quarrying, including geological, environmental, economic and cultural aspects, with particular attention to the sustainability of extraction

practices and to the potential exploitation of the decommissioned or abandoned mining assets, including mining wastes piled up over time.

To each coded mining site has been associated information related to data sources, type of mining site, state of activities, type of extracted ore, type of management, presence of park/museum and environmental conditions. So far, all the active quarries and mines within the national territory have been identified and georeferenced. About 90% of the mines opened since 1870 have been located too.

Mines in Italy

Italy has a long history of mining extending back to the Pre-Roman times. It is our intention to identify all of the ancient mining sites. At present, more than 3,000 sites have been identified in the period since 1870 (Unification of Italy) to 2018 (***Figure 3***). Exploitation of metallic minerals (now zeroed out) was widespread in the Alps, Tuscany, Calabria and Sardinia. Sulfur mines (also zeroed out) were operating in Sicily and to a lesser extent, in Marche and Romagna. Until 1950, Sicily was the world's largest sulfur producer. Coal (mainly lignite) was exploited along the alluvial plain of central Italy. Currently, 107 mining concessions are active but only 67 mines are operating with the extraction of industrial minerals, mainly for ceramic industry, cement marls and salt (***Table 1***). None of the operating mines involves extraction of metallic minerals. The Pb-Zn-Ag Gorno mines (Lombardy), which ceased operation in 1980, are scheduled to return to production in 2020-21. Several prospecting permits for metallic minerals (Ni, Pb, Zn, Co, Au, Ag, Cu) have been granted in the Alpine region (Piedmont and Lombardy) (Carta *et al.*, 2017b; ISPRA, 2019).

Quarries in Italy

Because of Italian geological complexity and lithological diversity, the exploitation of aggregates and dimension stones from quarries concerns a wide range of rocks. All active quarries sites have been georeferenced with an evaluation of the state of activity by means of regional data or remote sensing analyses (***Figure 4***). At the end of 2017, 4,368 quarries were authorised but, due the sectorial economic crisis, only 2,630 were operating. Of the authorized sites, 67% concern the extraction of "sand, gravel and debris" (1,321 sites) and "limestone, marl and chalk" (1,646 sites) (***Figure 5***). Sand and gravel quarries are widespread throughout the national territory along the valleys and

Figure 4: Distribution of authorized quarries in 2017.

plains, with an obvious concentration in the Po Plain. At a national level, limestone, most of it crushed for aggregate production, is the most exploited lithology in Apulia, in the central Apennine, in western Sicily, northern Lombardy and in Veneto and Friuli-Venezia Giulia regions. This category includes also travertine, intensely extracted mainly in the district of Guidonia-Tivoli, near Rome. Sandstone extraction takes mainly place in the Northern Apennine. The exploitation of effusive igneous rocks is developed in Sicily and Campania active volcanic areas, in the Pleistocene Latium volcanoes (tuff, basalt, pozzolana) and in the Permian of Trentino-Alto Adige (porphyry). Intrusive igneous rocks mainly characterise quarrying in Sardinia (granite). Metamorphic rocks are intensively exploited in the Alpine arc, especially in Piedmont (gneiss), in the Apuan Alps (Carrara Marble) and in Liguria (slate) (Carta *et al.*, 2017b; ISPRA, 2019).

Mining waste from a circular economy perspective

Extractive industries (mines and quarries) have provided, and currently provide, mineral raw materials that are essential to related downstream industries and economic sectors, but at the same time they have generated huge quantities of mining wastes. These wastes may include waste rocks (e.g. overburden or wall-rock), mineral processing wastes (e.g. tailing sand) and exploration/resource drilling wastes (e.g. drill cuttings/chips) and they may still contain a fraction of valuable and potentially recoverable mineral (***Figure 6***). The above-mentioned wastes may represent potential secondary resources of critical and other mineral raw materials, which are currently in growing demand and for which the EU depends on imports.

After numerous accidents caused by the inadequate management of extractive wastes, the EU Commission issued the Extractive Waste Directive (D 2006/21/EC) in order to limit their production and to prevent or reduce, as far as possible, any adverse effects on the environment or on human health. This Directive states that in active mine areas the extractive waste is subject to a *management plan* for the treatment, recovery and disposal with maximum utilisation of the extracted waste resource (Article 5); while for closed or abandoned mine areas the extractive waste is subject to the *inventory* of waste facilities which cause serious negative environmental impacts or human health (Article 20).

Concerning Italian mining sites, attention is given to extractive waste catalogued according to Article 20 of 2006/21/EC Directive. These are wastes produced in the past and contained in closed or abandoned storage facilities. The term closed means a

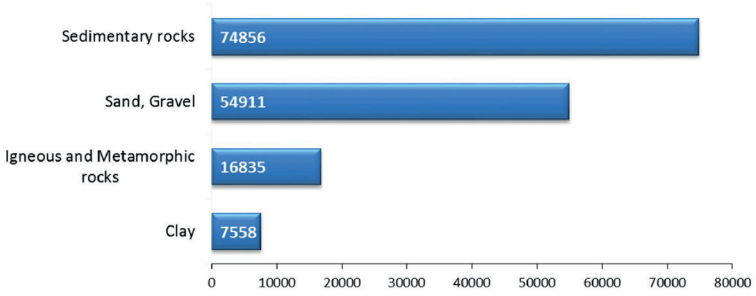

Figure 5: Quarrying production in 2017 (tons).

Figure 6: Extractive Waste Facilities. On the left Monteponi Mine red muds, on the right Masua Mine tailings pond.

Table 2: Comparison between CRM (EU CRM list, 2017) and Italian inventory of extractive waste closed/ abandoned facilities (art.20 of Legislative Decree, 2008).

CRM	Potential minerals in the scraps	Extractive Waste
EU CRM List – updated every 3 years [COM(2017) 490 final]	Antimony	Italian Inventory... (art.20, D. Lgs. 117/08)
	Beryllium	
	Bismuth	
	Cobalt	
	Fluoride	
	Vanadium	

storage facility that no longer receives waste, stockpiled in historical time and before the adoption of the Mining Waste Directive (2006/21/EC), usually disposed of in heaps and ponds.

Each Member State has implemented the directive in its own legal system and, for Italy, Legislative Decree No. 117/08 was issued prescribing the realisation of "the Inventory of Extractive Waste Facilities" (Legislative Decree 117/08, Article 20). The information catalogued in it, in some cases, may point out wastes potentially containing critical raw materials (CRMs) in relevant quantities and concentrations (e.g. indium or germanium in zinc mineral processing tailings or gallium in wastes related to bauxite mining), thus allowing the evaluation of their possible recovery. Particular attention should be given to those facilities (closed or abandoned) that are assessed as having high potential amounts of CRMs and other valuable minerals and/or metals on the basis of the previous extractive activity or analytical sampling data.

Currently, no database, neither in the EU nor in Italy, reports the volumes, mineral resources and related metal grades of the extractive waste deposits (for closed/ abandoned and active mines), classified on the basis of the main mineral commodities primarily exploited, the types of waste, and the volumes and compositions of the different waste streams produced across mineral value chains. Nevertheless, from a circular economy perspective, extractive wastes are considered to be a potential source of valuable minerals and/or metals, including CRMs, that may be targeted for recovery. In fact, increased recovery of CRMs from extractive wastes can 1) reduce the amount of storage and stockpiled extractive waste, and mitigate or even minimise the associated environmental impacts and 2) lead to adjustments in primary mining by contributing to securing the growing supply needs of minerals (Mathieux *et al.*, 2017; Eco-Efficiency *et al.*, 2019a).

So far, the recovery of CRMs from extractive waste is rather low (e.g. <1% for rare earths, In, Ge), but old mines often focussed on the production of one or few commodities, while recent technological progress increasingly allows the production of additional co-products and by-products. Thus, it is possible that associated minerals and/ or elements, not known, poorly detected or not exploited during past mining activities are still present (and potentially exploitable) in the old extractive waste facilities. Furthermore, low-grade ores with concentrations below the cut-off grade at the time of mining may become extractable and their recovery may become economic due to technology changes, growing demand and elevated market prices for the minerals and metals contained in the ore.

The aim of the circular economy is to boost economic growth by promoting the implementation of resource- efficient practices and creating many opportunities for the rational use of raw materials. The European Commission recognises the importance of the circular economy and is developing and implementing an action plan outlining new product requirements and new principles for assessing environmental performance using the life cycle assessment method (Ghisellini & Ulgiati, 2019). At the same time the EC promotes the application of a circular economy in assessing the mineral resource and metal recovery potential of old/historical extractive wastes, considering it as best practice in extractive waste management plans (Eco Efficiency *et al.*, 2019a; 2019b). The dimension of the circular economy in Italy, in terms of added value, is worth just under 1.5% of the national added value. In 2014, there were 47,487,404 tonnes of mining wastes deriving from extractive activities (processing wastes), representing a percentage of 37% of the total wastes volume in Italy (CONAI, 2018).

In fact, available analytical data of several extractive wastes show elevated contents of metals which are also included in the latest European list of CRM (updated every three years) (***Table 2***), enabling them as potential resources of valuable minerals and metals. Those that were previously wastes have become new sources of raw materials for other production cycles and well-designed new products that enter the sustainable revolution that the circular economy wants to model (Moschini & Bompan, 2017). Recovery and reuse may become an integral part of the processes, together with all those measures aimed at reducing production costs, less dependence on critical

raw materials, a dynamic contribution to the growth of job opportunities, and the containment of pollution from waste and emissions during the production process.

Finally, even in the extractive field, the circular economy represents an extraordinary opportunity to bring about the desired revolution in optimising the use of natural resources and sustainable waste management, limiting the number and size of landfills, and increasing the recovery rate from wastes.

Conclusions

The many aspects and issues linked to the extraction of non-energy mineral resources are, at the Italian national level, uneven and incomplete. Up until now there has been no national IT structure shared between the state and the regions that is dedicated to the integration of the geological, mining, environmental, cultural and management aspects of the extractive activities.

By means of the creation of the GeMMA database, the Geological Survey of Italy (ISPRA) intends to share available, harmonised and INSPIRE-compliant mineral information with the European Union Raw Materials Knowledge Base (EURMKB). In addition to the basic data coming from other existing databases, the database is also designed for gathering a series of information related to environmental restoration of the sites, the management of mineral waste, and recycling plants for construction and demolition materials.

The database testing period will be carried out in collaboration with the Regional Geological Surveys and with the Regional Agencies for Environmental Protection, also trying to promote agreements between the various regional offices, including those responsible for extractive activities. An advanced version will then be shared with ISTAT (Italian National Institute of Statistics) and with the Raw Materials Laboratory, as well as with the concerned ministries and regions, in order to achieve a participatory, integrated and comprehensive result.

In other words, it is deemed necessary, in compliance with the specific skills of the various territorial levels, to create flexible conditions for dialogue and convergence governed by the principle of loyal and equitable collaboration. Within these challenging discussions, the Geological Survey of Italy hopes that GeMMA will become a valuable support tool for the development of national and regional policies oriented towards sustainable production and the efficient use of primary and secondary mineral resources, addressing and targeting the implementation of the circular economy.

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