



Rethinking the concept of small-scale mining for technologically advanced raw materials production

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ABSTRACT

The purpose of this paper is conceptual analysis and critique, informing development of a modern technologically-advanced small-scale mining (SSM) concept. The need for SSM has recently been articulated in a European mining policy context. In an attempt to secure access to minerals, European strategy includes the development of new approaches to the extraction of resources from ore deposits, including by SSM operations. However, the application of traditional thinking and definitions of small-scale mining to a European context is problematic, such that the evolution of modern smaller scale mining also requires re-thinking of the underpinning concepts. We discuss various company structures, scales of mining and their specific features. We differentiate SSM from “artisanal small-scale mining” (ASM) and discuss its relationship to “large-scale mining” (LSM). From this analysis, we distill the key features and criteria of SSM and raise important questions concerning social and environmental sustainability in relation to SSM. We suggest that greater definition of what constitutes technological small-scale mining in a European context will substantially improve further research in the development of mining solutions and contribute to the discussion on the future of mining both within and outside of Europe.

1. Introduction and objective: a requirement for smaller scale mining in Europe

Over the last decade, the European Union has articulated that its stability and the competitiveness of its economy are dependent on the import of raw materials, in some cases from vulnerable supply chains. In order to improve supply of raw materials, initiatives have been developed that include a renewed interest in the development of mining operations inside the European continent (Küblböck, 2013; Massari and Ruberti, 2013). Rapid development of raw materials extraction in other parts of the world and rising commodity prices simultaneously complicate and necessitate the stimulation of a regional mining industry, which requires political support as part of a European mining agenda (e.g. Strategic Implementation Plan SIP, 2013a). This renewed ambition for mining inside Europe includes the idea of small-scale mining, both in the Raw Material Initiative and in the European Commission Reports on Critical Raw Materials.

In 2008, the European Commission launched The Raw Materials Initiative, which set a framework for a more reliable and secure access to raw materials. It consists of three main strategic pillars of implementation that aim to: (a) ensure access to raw materials from international markets; (b) foster sustainable supply from European sources; (c) boost resource efficiency and recycling (European Commission, 2008). The

Commission has identified mining scenarios that have the potential to contribute to raw materials production in Europe: mining operations at greater depths, mining of non-conventional surface deposits and mining of small deposits (SIP, 2013a). Small deposits are included in exhaustive databases (e.g. ProMine, Minerals4EU) of known and predicted mineral resources in Europe. Such surveys are likely to have considered small deposits in Europe as sub-economic due to high exploration and infrastructure costs, or lack of appropriate technologies. The imperative to unlock small deposits in Europe has triggered activities towards understanding the geological, technological and economic step-changes that would be required. They suggest that both a reappraisal of existing mineral deposit maps of Europe and the potential for under-explored smaller deposits is required (SIP, 2013a). Pilot data analysis by the geological survey of France (Bureau de Recherches Géologiques et Minières, BRGM), using just 5 commodities as search criteria, established that a total of 201 known mineral occurrences across the European Union satisfied the end-member scenario of high-grade and low tonnage deposit (Estrade et al., personal communication 2018). The preliminary analysis suggests that there may be enormous potential for small deposit mining by SSM operations of a wide range of commodities, though this is not subject to any further determination of economic viability. Pellegrini (2016) further highlights that development of some areas with high mineral potential could be hindered by competition

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from other land uses, such as agriculture, forestry, housing and industrial zones.

Within the framework of the EU Raw Materials Initiative, the EC issued a list of 14 Critical Raw Materials (CRM) in 2011. The “criticality” of the raw materials is considered through the assessment of two components: economic importance, and supply risk. In 2014, the list was extended to 20 CRMs and 27 CRMs in 2017 due to an increase in the number of metals and semi-metal materials considered and the addition of an increasing number of non-metallic materials. However, some raw materials are present in all iterations of lists of CRMs. For example, the repeated inclusion of the rare earth elements (REEs) is unsurprising given that domestic reserves of rare earth minerals in Europe account for less than 1% of mining production, even though the potential for REE production in Europe is high (Goodenough et al., 2016; Rollat et al., 2016). According to EC estimates, the European Union is 100% dependent on rare earth supply from China (European Commission, 2018). The criticality of the REE for European industry is demonstrated by their use in the infrastructure required for the green energy transition, the European Commission initiatives to develop a low carbon economy, and recent legislative proposals in the *Clean Energy for All Europeans package* (June 2018). Small-scale mining may therefore be a viable solution for extracting metallic and semi-metallic commodities from ore deposits within Europe in order to reduce supply risk. The commodities listed as critical by the EC in 2017 also included biotic (coking coal and natural rubber) and rock (phosphate rock) resources. Small-scale mining in Europe will not reduce supply risks for some of these commodities, either because the natural resources (e.g. rubber) are not naturally occurring in Europe or because different quarrying and/or extraction processes are required for their production.

The European Innovation Partnership (EIP) on Raw Materials was introduced in 2012 to stimulate joint research and innovation in mining, with inputs from the member states, the research community, policy makers and other stakeholders groups (European Commission, 2014). It aims to link better the EU funding to industrial need and improve coordination in the area of raw materials (SIP, 2013a), and it identified a Priority Area for research and innovation entitled ‘Technologies for primary and secondary raw materials production’. The description of the Priority Area articulated that technological challenges along the entire raw materials value chain need to be addressed by production solutions that avoid environmental damage and engage society. Specifically, the Commission solicited research on the development of new sustainable, selective, low-impact technological solutions for mining of small mineral deposits on the land. The IMP@CT project, funded by the EC Horizon 2020 programme, is developing a small-scale, modular whole systems mining approach for responsible extraction and processing of small deposits, including deposits of CRMs. The research is founded on the premise that a climate of increasing costs (including those relating to environment) from large deposits at decreasing grade may create a space in the market for small-deposit conventional mining with technological solutions that increase competitiveness.

Heterogeneity in the terminology has been cited as one of the main challenges facing attempts to reliably analyse European data relating to issues of raw materials supply (SIP, 2013b). The Strategic Implementation Plan for the European Innovation Partnership on Raw Materials discusses the importance of standard terminology for reporting on raw materials. It is also suggested that EU reporting standards should be based on internationally-accepted conventions with regard to raw materials (SIP, 2013b).

In this article, we analyse existing concepts with the objective of developing a modern technologically-advanced small-scale mining (SSM) concept. As described above, European strategy includes the development of new approaches to the extraction of resources from ore deposits, including small, high-grade mineral deposits. But the application of traditional thinking and definitions of small-scale mining to a European concept of small-deposit mining is problematic. The development of European (and other) smaller scale mining operations thus

requires a fundamental re-evaluation of concepts. Integral to the conceptual analysis is the development of the sustainable mining agenda. A new concept inevitably raises important questions for modern mining, which must proactively anticipate and mitigate sustainability and responsibility challenges. The starting point of the analysis is in European mining policy development, but the concept as such is of course universal.

As Branch and Rocchi (2015, 22) have noticed, “*the concepts serve critical functions in science, through their descriptive powers and... as the building-blocks of theory*”. When concepts are immature, research is needed towards identification and development of the conceptual bases of knowledge. The work on conceptual development employs methods of concept comparison, clarification, or correction, using the literature as data (Hupcey et al., 2001).

The research process in this article follows the classical ideas of Batey (1977), who defined four stages of conceptual research: 1. the description of the phenomenon which is to be addressed by the research; 2. the state of knowledge which exists about the concepts which are present in the phenomenon, 3. the scientist’s logical construction or mapping of the concepts in light of that knowledge, and 4. the specific part of the phenomenon which is to be examined through the empirical or interpretive phase of the research.

Thus, based on previous research literature and mining practices, we review and discuss the structures of the mining industry and different concepts used in order to describe the various scales of mining. We start by describing company structures (majors, intermediate and juniors), and proceed to a more detailed analysis of the artisanal mining concept. Subsequently, we define the features of small-scale mining (SSM) and continue to discuss the embodied sustainability challenges. Our literature review is integrative. It summarizes the literature on a phenomenon of interest, with a view to deriving some sort of conclusion about substantive and conceptual issues of the phenomenon (Branch and Rocchi, 2015, 19). It is augmented by the expert discussions, workshops and experiences obtained within the Horizon 2020 IMP@CT project. We ultimately describe the features and different connotations of small-scale mining and develop the definition of the SSM concept. In the last section, we present some frames of reference for features of SSM in relation to various environmental and social sustainability criteria.

2. Structure of the global mining industry

Mining companies are often divided into three categories according to size: majors, intermediate and juniors. The structure of the global mining sector is heavily weighted towards a relatively small number of “majors”, which control the most active production sites in the world (GHGm, 2008). According to some estimates, the top 150 mining companies make up less than 4% of the number of industry players but produce 80% of global metals (GHGm, 2008) and account for the lion’s share of international trade transactions (Raynard and Forstater, 2002). Annual analytical reports provided by major think-tanks are strongly fixed on the performance of large companies, and sector overviews are limited to the activities of TOP-40 (PWC, 2016) or TOP-50 (PwC Australia, 2012) mining companies. Globalization in the mining sector has increased the dominance of large companies and transnational corporations. This is readily observed in developing economy countries, where actions of the IMF and World Bank towards liberalization of countries’ mining sectors in the 1980–1990s created innumerable opportunities for multinational mining companies (Hilson and Haselip, 2004; Campbell, 2009).

“Intermediate” mining companies are usually defined as those which operate one or more small mines (Thomson and MacDonald, 2001). However, the evidence relating to their performance is quite limited in the research literature and sectoral performance reviews. Everett and Gilboy (2003) stated that, at the end of the 1990s, the number of “intermediate” companies had dramatically fallen. Many intermediate companies have been forced to merger and acquisition transformation

with larger companies in order to survive in challenging market and regulatory conditions. This evolution of the structure of the mining industry further reinforced the dominance of the large mining companies (Bogden, 2002), such that the “big three” BHP, Rio Tinto and Anglo American collectively comprised 77% of the top 10 companies in terms of market capitalization and 71% in terms of revenue in 2002.

The term ‘junior’ is used to denote those companies that are involved in exploration or those mining companies that exclusively extract a single commodity, such as gold. The “junior mining companies” account for less than 1% of global metal production (GHGm, 2008). However, most of the global spending on exploration, which has increased five times over the past twenty years, was raised by junior companies (Dougherty, 2013). The migration of the mining industry over the last two decades into the southern hemisphere (Bridge, 2004) has pre-determined the characteristics of modern junior industry players. While most junior companies are registered in such countries as Canada, Australia, and the US, they conduct most of their exploration in the developing world (Everett and Gilboy, 2003). In the mining cycle, they perform as start-ups in the new mining areas with the aim of selling their discoveries to major companies. Quite often they work in strategic partnership with the major companies, such that the latter ramps up production after juniors have done the exploratory work (Everett and Gilboy, 2003). In this way, Dougherty (2011) explains that junior mining companies have often been assigned to accomplish the industry’s dirty work, which enables larger companies to benefit from juniors’ rent-seeking strategies while deflecting responsibility.

The structures of the global mining industry at company level can be described as a hierarchical system, dominated by “major” (senior) who have an established practice of steering sectoral trends, and “intermediate” (or mid-tier) and “junior” companies that have corresponding practices (see e.g. Thomson and MacDonald, 2001; Dougherty, 2013). Artisanal, small-scale mining (ASM) does not sit neatly within the hierarchical and regulated global mining system. The relationship of ASM to large-scale mining (LSM) by major mining companies has often been conflictual where both types of miners compete for the same resource, occupy the same concession or perceive one another as a threat (World Bank Group, 2009; IGF, 2017). Mineral governance frameworks tend to favour foreign direct investment by multinational companies over ASM, such that there are significant power imbalances, clashes over claims and the classification of ASM mining as illegal or extralegal (Siegel and Veiga, 2009; IGF, 2017). The relationship between LSM and ASM is evolving as a consequence of societal pressure and policy from international development agencies with initiatives relating to formalization of the ASM mining sector, co-habitation of concessions by ring-fencing of LSM and ASM zones and facilitated discussions (Siegel and Veiga, 2009; IGF, 2017).

3. Artisanal mining (ASM) as small-scale mining

For the last twenty years, discussions about “small-scale mining” have largely referred to artisanal mining activities. Terms have been used interchangeably, so that “small-scale mining” has effectively become a synonym for “artisanal small-scale mining” (ASM) (see e.g. Hilson, 2006; Aryee et al., 2003). The use of the acronym ASM in this manuscript does not extend to small-scale mining that is not artisanal.

Artisanal small-scale mining typically describes a “poverty-driven activity, usually practiced in the poorest and most remote rural areas of a country by a largely itinerant, poorly educated populace with little other employment alternatives” (World Bank, 2013). The OECD (2013) has defined ASM as “formal or informal mining operations with predominantly simplified forms of exploration, extraction, processing and transportation, which is normally low capital intensive and uses high labour intensive technology”. ASM can include men and women working on an individual basis as well as those working in family groups, in partnerships, and enterprises involving hundreds or even thousands of miners (OECD, 2013). 6 million people were directly engaged in ASM in

1993, rising to 13 million in 1999 and to 30 million in 2014, and more than 40 million people were directly engaged in ASM in 2019 (IGF., 2017; Delve platform, 2019). Since ASM is labour-intensive and the notion of “small-scale” relates to capital investment and the size of local enterprises, it may be expected that ASM production and revenue figures might be quite moderate and share a non-significant fraction of the global mining economy. The evidence is to the contrary and, in some cases, the cumulative amount of the mineral produced by ASM can surpass the amount produced by large-scale operations (Aubynn, 2009; Zvarivadza and Tholana, 2015). According to very rough estimates, artisanal and small-scale mining produces around 15–20% of global minerals, including 80% of all sapphires, 20% of all gold, and 20% of diamonds (Buxton, 2013). ASM is also a major producer of raw materials strategic to electronics manufacturing, and accounts for 26% of global tantalum production and 25% of tin production (IGF., 2017). Similar to the production figures, the socio-economic impact of artisanal small-scale mining is far from small. The number of people employed in ASM is an order of magnitude greater than in the industrial sector: While 30 million people were directly employed in ASM in 2014, only 7 million people were working in industrial mining in 2013 (Buxton, 2013; IGF., 2017). Moreover, ASM makes a significant contribution to informal economies in as many as 55 countries (Seccatore et al., 2014; Buxton, 2013; Jennings, 1999).

A recent query of Scopus using the search term (keyword, title or abstract) “small-scale mining” (Fig. 1) returned approximately 580 publications dealing with the issues of artisanal small-scale mining. The search demonstrated that the body of research literature describing small-scale mining is expanding, but this focuses on artisanal small-scale mining (Hilson and Potter, 2005; Siegel and Veiga, 2009.) The search further demonstrated that the topic of small-scale mining has been developed largely over the last one and a half decades, with a first peak in 2014 at 47 publications and a second peak in 2017 at 64 publications. Since the majority of publications focus on case studies of ASM in developing countries, the notion of small-scale mining has become closely associated with artisanal mining activities (Hilson and McQuilken, 2014; Lahiri-Dutt, 2018): the terms “small-scale” and “artisanal mining” are used interchangeably or with very little attention towards distinction of artisanal (manual and/or somewhat mechanized) mining and small-scale mining using advanced technologies. Barreto (2011) suggests that there is a tendency to separate ASM from formal mining activities and to add a development approach to discussion. Yakovleva (2007) also argues that the description of 80% of ASM as illegal serves to place small-scale mining outside of formal economic and regulatory frameworks. Such a situation establishes limits on the application of the term “small-scale” to other contexts and identifies a need for new research to address the issues of modern (not artisanal), low-impact and sustainable small-scale mining operations.

4. Scales of mining

Scale of mining may refer to the spatial and environmental footprint of a mine. The question of scale as it relates to an individual mine can variously be addressed in terms of size of a mineral deposit, in the extent of land-use, in tonnes of concentrate production, in the scale of environmental impacts, in employment and in temporal duration. For example, world-class or ‘Giant’ ore deposits are described in terms of grade and tonnage (Laznicka, 1999), and they are often operated by the majors. But division of the various categories of scale of mine based solely on company size will lead to a number of inaccuracies. It is possible for a junior company to develop a largescale mine, and vice versa, it is possible for a major company to own a small mine. Therefore, it is important to differentiate between company size and scale of mine, such that descriptions of scale have clarity.

The different scales of mining are not equally represented within the industry, especially as they relate to company size. A reduction in the number of smaller companies at the end of the 1990s and increasing

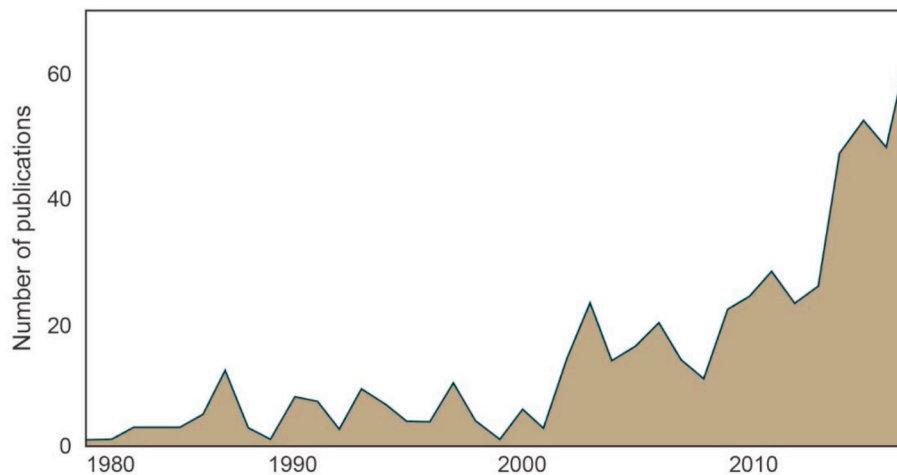


Fig. 1. Frequency of publications relating to “small-scale mining” in the Scopus database, by year.

dominance of the majors demonstrates that the current mining paradigm, which enables majors and large-scale mining, cannot readily be scaled down for smaller companies and small mines. In order to develop a clearer understanding of how the scales of formal mining projects can more effectively co-exist, the fundamental issue around meanings and definitions needs to be clarified. In order to draw comparisons between the various scales of mining, we propose the use of terminology as follows:

- Large-scale mining (LSM) is extraction from ore or mineral deposits by companies with substantial labour forces that are employed across large sites, working a deposit using (technologically) optimized approaches to develop economies of scale.
- Artisanal mining (ASM) is extraction from ore or mineral deposits by formal or informal mining operations with low investment and the use of technologies that are highly labour intensive. The scale of mining can either be small (relating to self-employed status of mine workers) or large (relating to the size of the collective and/or deposit). It is mainly in developing countries.
- Modern small-scale mining (SSM) is extraction from ore or mineral deposits using low-impact, potentially short-term, small-footprint, regulated mining operations and technologies that are usually not labour-intensive. The approach is suitable for, but not limited to, small ore deposits.

Applying the traditional categorization of mining companies to our discussion about non-artisanal small-scale mining activities, we can apply the description of “intermediate” to those companies that operate one or more small mines (see e.g. Thomson and MacDonald, 2001). However, the status of an “intermediate” company remains unclear when no comprehensive research on the performance of “intermediate” mining activities has been published. Additional terms that have been used in the published literature are “mid-tier resources companies” (Lyons et al., 2016) and “smaller mining companies” (Shankleman, 2009). In 2001, the ITDG (Intermediate Technology Development Group) defined small-scale mining in terms of a given production ceiling and the level of sophistication by which minerals are exploited. In this way, “small-scale mining is any single unit mining operation having an annual production of unprocessed material of 50, 000 tonnes, or less as measured at the entrance of the mine” (Dreschler, 2001). Small-scale mining could be amenable to operation by any scale of company. This includes small- and medium-sized enterprises (SMEs), defined by the European Union (2003) as having at most 250 employees, an annual turnover not exceeding €50 million, and a maximum €43 million annual balance-sheet total. For its application to the mining industry, the European Commission definition for the SMEs could also be extended to

include indicators such as “company profit”, “invested capital”, “market position”, production and sales volume (Loecher, 2000).

We consider that a new definition of a small company in the mining industry may also be required (in addition to SSM), where commercial activities are not restricted to exploration or to production of a single commodity. The definition of a junior company overlaps with that of an intermediate or mid-tier company. It refers mainly to the functions and business ideas of certain companies, not directly to the scale or size of the company or its operations.

The lack of extensive research relating to formal mining activities in small deposits by small and medium enterprises contributes to the accepted and interchangeable use of the terms small-scale mining and artisanal mining. LSM and ASM are frequently used in comparative studies representing two major (and opposite) paradigms of mining operations (e.g. Aubynn, 2009; Luning, 2014), while formal mining activities that happen to be “not so big” attract rare attention. Their operations remain largely invisible, particularly in comparison to multinational corporations. Indeed, the economic impact of small to medium companies is quite moderate and they do not compete with large-scale mining business in terms of revenue. Smaller environmental and social impacts than those in large-scale operations (Arias et al., 2013; Hilson, 2001) have correspondingly attracted less attention in the social and environmental research arena. The discourses on sustainability of mining operations have also been much influenced by narratives and practices for projects of larger scales (de Villiers et al., 2014; Fonseca et al., 2014).

In the following, we concentrate on more detailed description and definition of small-scale mining (SSM), which refers to the scale of mining, not to the size of the mine-operating company.

5. A refinement of the concept of small-scale mining

In this chapter, the aim is to refine the concept of small-scale mining into that of technologically-advanced (non-artisanal) small-scale mining (SSM). Current collaborative research was facilitated by the Horizon 2020 IMP@CT project, including its expert workshops. It identified the following characteristics that can, in some combination, describe modern SSM:

- Exploration of, and extraction from, small but high-grade or complex deposits.
- Small-scale operations in larger deposits with small economic margins.
- Shorter duration of mining due to the small mineral reserve or economic market conditions.

- Mainly underground operations, with selective mining and backfill options.
- Use of advanced extraction and processing technologies, and potentially a high level of automation.

The implications of such (exploration and) extraction are that:

- It is possible to adopt small-scale flexible and modular technology that can easily and rapidly be deployed on site, and/or be moved between mine sites.
- It is possible to develop “SOSO” (“switch on – switch off”) mines that operate when world market prices are favourable and are under care and maintenance when prices are low.
- Operations will employ few workers compared to LSM, but the need for a trained workforce is high.
- The infrastructure that is needed is significantly smaller than in LSM.
- Depending on the technologies adopted, the small-scale mine has the potential to be eco-efficient with minimal use of energy, land, water and chemicals for processing.
- Economic costs are moderate for starting and closing the production, such that the investment required is minimized.

The traits presented above are essentially different from the traditional understanding of ASM. Compared to ASM, exploration and mining of small, high-grade or complex deposits in Europe will be highly regulated and have higher overheads, so that it must be efficient and cost-effective. Efficiency will most probably be achieved through the use of sophisticated extraction and processing technologies, a greater degree of automation, and the employment of small, highly-trained workforces. In a technological context, “small-scale” mining is the reverse of ASM but the analogy with ASM can be considered further. The European Commission has avoided the issues around “small-scale mining” by promoting research and innovation in the area of “small-deposit mining”. However, ASM on large deposits can be described as “small-scale” because each worker can be self-employed.

There exists the possibility that small-scale operations using sophisticated technological approaches to extraction could be used on large deposits in Europe for environmental and societal reasons. This highlights that the term “small-deposit mining” can be limiting. We argue, that in order to create a small-scale mining concept that fits well into a formal mining context, it is important to distinguish conventional understanding of small-scale mining as artisanal from new modes of “small-scale mining”. There is an assumption that small-scale mining would be dominated by operations of smaller mining companies including small and medium enterprises, defined as companies that have less than 250 workers. But smaller and staged operations are now considered as possible solutions to reduce financial risk in large projects, which arises from high capital intensity, uncertainty in commodity prices and reliance on long-term forecasting models (Quirke et al., 2019). Thus, the relationship between scale of operation and scale of company is not straightforward. However, in the current economic paradigm, small complex deposits are likely not to be the target of large mining companies that continue to develop mines in large deposits often at low grades (Bogden, 2002; Laurence, 2011). The economies of scale for maximum economic return continue to be used by large mining operators to minimize investment risks.

6. Small-scale mining in the context of society and sustainability

Important questions for developing modern mining today in general, but also in the context of small-scale mining, relate to sustainability, responsibility and social acceptance. Mining has a long history of causing negative environmental and social impacts, and problematic management of local community relations. The relationship between mining industry and society is increasingly acknowledged as critical in evaluating the possible consequences of mining development (Solomon

et al., 2008; Franks, 2015; Tiainen et al., 2015; Sairinen et al., 2017). It has often been argued that the future of mining in Europe is dependent on how the industry can answer to the requirements of ecological and social sustainability. On a European level, “Public awareness, acceptance and trust” is cited as one of the main action areas for improving the framework for regional production of raw materials (SIP, 2013b).

The dominance of large-scale mining operations (Banks et al. 2013) influenced certain trends in the sustainability discourse of modern mining. Various negative environmental and social impacts that larger mining projects may cause were typically used as the most common starting point for discussing mining sustainability (Giurco and Cooper, 2012; Mancini and Sala, 2018; Mudd, 2007). Thus, the idea of “sustainable mining” adopted in the late 1990s has mainly been initiated by major mining companies in response to critique presented by the environmental movement (Kapelus, 2002; Franks, 2015; Amezaga et al., 2010; Azapagic, 2004). For example, the “Global Mining Initiative”, which articulated approaches towards sustainability for the whole mining sector, was established by nine of the largest mining and metal companies worldwide (Global Mining Initiative (GMI)). It seems this trend has continued. In the discussions on the sustainability of industrial mining operations, too little attention has been given to the heterogeneity of the mining sector and different scales of mining were not equally investigated in relation to their sustainable performance.

The sustainability issues of ASM have also been widely discussed and studied (Hilson and McQuilken, 2014; Franks et al., 2020; Luning, 2014). However, ASM has many features that differ from large-scale industrial mining, such that ASM sustainability discussions were not placed within the sustainability mining discourse of the global mining system. Thus, a focus on sustainable performance of LSM, rather than ASM, continues to dominate the current industrial mining paradigm and underpins the guidelines for the entire mining industry.

In summary of the analysis, there should be an attempt to account for various scales of mining operations, multidimensional aspects of business, technology, society and environment relations. The evaluation of the various categories based solely on company designation, production or economic perspectives will lead to a number of inaccuracies. These will disadvantage consideration or development of technological and societal adaptation. Assessment of mining operations on limited criteria, for example, focusing on technology-level alone, is flawed. Technologies are employed at all types of mining operation, as appropriate to the mining context, scale and education of work-force. Assessment of level of technological adaptation requires metrics that will not always be readily available and levels of technological sophistication are viewed differently by those working in the global mining sector and the development sector.

When considering the potential for development of small-scale mining in Europe, it is essential to explore and understand the social and environmental impacts of SSM and the level of their management. Identification and effective management of social and environmental impacts are key to responsible and acceptable mining activities. When considering the characteristics of small-scale mining, we can preliminarily identify the following features of society and environment relations:

1. *Size of workforce as a function of unit area* of the mine site in operation can be very low compared to ASM and could be slightly higher than LSM, depending on the level of automation. It is considered a better metric than size of company because the potential exists for majors to adopt small-scale operations in certain contexts.
2. *Sophistication of technologies* will be higher than in ASM due to the capital start-up costs (CAPEX) for infrastructure, whether portable or otherwise, and the ongoing need for maintenance and fuel. Investment for CAPEX is more readily available to the formal mining community.

3. *Rate of production* will be significantly higher than in ASM and significantly lower than in LSM. Throughput of an onsite processing plant at a small scale mine may be between 5 and 50 tonnes per hour.
4. *Small land use* of a mine and a processing facility will provide a greater opportunity to develop integrated land management that includes mining operations, and that facilitates reclamation.
5. *Short temporal duration* will accompany small-scale mining (about 2–10 years).
6. *Limited socio-economic impacts*, such as the level of employment, local/regional tax revenues and royalties, will usually accompany quite small and short-term mining operations. Thus, the local community and regional economy cannot expect large or long-term contributions to local development.

The short-duration of mining operations and reduced socio-economic impacts of SSM have both positive and negative implications. While LSM typically causes extensive changes in local demographics, the local community will usually not suffer a big influence or disturbance from the small-scale mine culturally or socially, for example in terms of population structure. The relatively small workforce of SSM may reduce many of the negative side-effects related to immigration, including increased prices of housing. In small-scale mining that is legally and environmentally well-regulated, the scale of environmental impacts and risks should be smaller than in both large mines and ASM, although the risks are dependent on the mined metal, technologies and the use of chemicals. This usually implies lower harm for neighbouring housing, other livelihoods and businesses in the area, but it also implies that communities may not be able to expand economically as a result of mining activity. Difficulties may arise for people who perceive that mining projects of all scales result in the same consequent economic development. The recognition of the various scales of mining is therefore extremely important in relation to the sustainability discourse. The sustainability agenda that today considers the mining industry as predominantly large scale and as an engine for regional development and poverty reduction (Pegg, 2006) may not be suitable for SSM. Critical questions for operating SSM may include whether SSM is of an extent that can contribute to local development and whether a company has adequate resources for extensive social performance. It may be that environmental and socio-economic limits could favour SSM by sophisticated and light technologies on large deposits, as well as on small mineral and ore deposits.

7. Conclusion: Re-thinking the concept of small-scale mining

The task of this article was to analyse extant concepts and develop a modern technologically-advanced small-scale mining (SSM) concept. There exists a potential for SSM in a European mining policy context and industry. SSM has the potential to operate on small, high-grade deposits and on large deposits to minimize economic risk. For such potential to be realised, the conceptual frameworks for SSM need to be developed, which requires clarity around the description of the structure of the mining industry and the metrics that are used to describe the scale of mining.

Though the term “small-scale mining” has been widely used in the extractive industries, its meaning has become synonymous with practices that are globally recognized as “artisanal small-scale mining”. At the same time, sustainability discourse and research have been oriented around the performance of large mining operators. Thus, mining activities that happen to be “not so big” compared to large-scale mining operations attract rare attention and remain largely invisible. In relation to sustainability performance, they were usually perceived just as a miniature version of a large mine or company, for which the agenda can be scaled down (Jenkins, 2006).

We have positioned the concept of non-artisanal modern “small-scale mining” in relation to the current dual mining paradigm of large-scale and artisanal small-scale mining operations, by describing its features

and likely impacts, and delineating a reference frame for further discourses. To avoid the ambiguity of the definitions, we propose a refined typology for large-scale (LSM), small-scale (SSM), and artisanal small-scale mining (ASM), which may provide more useful descriptions for the different types of mining operations. We have avoided description of the concept simply in terms of size of deposit, extent of mechanization or automation, or costs, since we perceive that the concept of non-artisanal small-scale mining can be applied in multiple scenario and that the term is otherwise at risk of becoming too restricted. The potential also exists for the intermediate space occupied by modern small-scale mining to be utilized in the future by all sectors of the mining industry.

Sustainability of smaller mining operations is a new and perhaps fruitful direction for future research. The traditional understanding of mining is an activity which inevitably affects the communities by degrading the environment, using large infrastructure and displacing people from their traditional livelihoods. This understanding still drives general perceptions of the mining industry and fuels societal concerns towards new mining initiatives.

Our study suggests that one of the fundamental questions is whether the existing concepts around sustainability and Social License to Operate can simply be scaled down for smaller forms of mining operations or whether the concepts should be re-evaluated, with particular attention to “scale”. This would require a more detailed assessment of how the application of new mining approaches affects environmental and social sustainability. Thus, discussion around social acceptance of small-scale mining projects requires recognition of the specific features of mining operation and its potential environmental and social impacts. This may mean taking into account, for example, the potentially short-duration of mining operations and reduced socio-economic impacts that can have both positive and negative implications.

Furthermore, empirical validation of the concept of modern small-scale mining is needed. Since the SSM concept has not previously existed, there is no available data yet about the relative share of its value in the mining sector as presented here. Thus, it is important to develop further the classification and statistics of mining projects as LSM, SSM and ASM. In addition, future research should include case-studies on operating small-scale mines and their impacts, involving detailed assessment of the application of new technologies on environmental and social sustainability.

CRedit authorship contribution statement

Olga Sidorenko: Conceptualization, Methodology, Writing - original draft. **Rauno Sairinen:** Methodology, Conceptualization, Funding acquisition, Validation, Supervision. **Kathryn Moore:** Conceptualization, Writing - original draft, Funding acquisition, Methodology, Validation, Supervision.

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Appendix A. Supplementary data

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