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Building a mineral-based value chain in Europe: the balance between social acceptance and secure supply

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Abstract
During the last years, the industry directly involved in the production and transformation of mineral raw materials in the EU has been responsible for ca. 40% of the value added associated with downstream manufacturing sectors, engaging more than 3 million of job positions. However, the EU is a net importer of ores along with a large diversity of metals and other mineral-derived products, including many of those involved in high-technology applications. This dependency makes the EU economy quite vulnerable to supply disruptions or other market fluctuations impacting the global supply chain for mineral raw materials. Ultimately, persistent shortages in supply represent serious bottlenecks to various economic activities running in the EU, jeopardising a significant number of jobs and many lines of the political agenda for the intended model of sustainable development. To overcome this potential weakness, a European mineral-based value chain emerges as a logical solution, particularly if designed along with a coherent scenario of re-industrialisation, research and development, technological innovation, continuous training of a high-qualified workforce, and internal investments prioritisation. In this context, the existing interlinks between activities related to the mining life cycle and the product life cycle in the EU must be revisited and transformed. The main drivers for these changes are (i) technological advances related to accelerated transitions towards digitisation, automation, and a low-carbon economy; (ii) societal, requiring higher fairness and increasing levels of transparency and proficiency from both the authorities and industry players; and (iii) relieving the reliance on imports of critical mineral raw materials.

Keywords Value-added chains · Mineral raw materials · Social-political acceptance · Corporate social responsibility · European Union

Introduction

Minerals and metals are the material foundations of economic development behind the progress of human society. Over time, successful paths of technological evolution in production chains have led to large-scale consumption and to the current high material (and energy) intensity of the economy. However, several recent signs consistently indicate the need for changes in the way mineral raw materials are used and their (primary and secondary) sources managed. These signs include widespread concerns about the material waste in modern societies and social inequities fostered by poorly regulated globalisation agendas, in addition to apprehensions related to environmental impacts triggered by fossil fuel combustion and heavy industrial activities. Accordingly, some expectations exist about reorganisation of the current raw material supply chains to better deal with these signs, which also represent the main grounds of societal reluctance regarding mining and mineral processing activities.

All the roadmaps oriented to eco-efficient and low-C intensity economies stimulate the reliance on a large number of minerals and metals whose increasing demand cannot be fulfilled on the basis of reuse, recycling, and/or substitution practices (Johnson et al. 2007; Vidal et al. 2013, 2017; UNEP 2017;

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Fortier et al. 2018; Hund et al. 2020). This means that material inputs derived from primary resources will always be necessary to balance the demand/supply ratio, filling the gaps of material stocks and flows in the economy that are not provided by secondary sources, even when suitably managed. In fact, the expected growth rates for demography and gross *per capita* incomes will boost spreads in consumption of conventional raw materials (Krausmann et al. 2009; OECD 2019). These spreads will be coupled with increasing diversity and growing amounts of specific metals needed to support the current and foreseen expansion of digital, clean, and disruptive technologies, reinforcing the trends towards (high-tech) metal-intensive economies (Kleijn et al. 2011; Fizaine 2013; Giurco et al. 2014; Frenzel et al. 2015; UNEP 2016b; Kavlak et al. 2015; Deetman et al. 2018). However, as reported in several recent assessments (UNEP 2009, 2010b, 2013a; Reck and Graedel 2012; EU Commission 2020a), ≈ 60% of the raw materials used in high-growth and high-tech industries have low (< 5%) recycling rates and are of difficult or impossible substitution, according to current know-how and technical procedures, and economic criteria. Furthermore, the production and market availability of these raw materials are subjected to a series of constraints that increase the likelihood of supply shortages in the near future, justifying their inclusion in various lists of critical raw materials (CRM), such as those produced for the EU (Coulomb et al. 2015; Graedel et al. 2015b; Delloite Sustainability et al. 2017; EU Commission 2018a, 2020b).

The ongoing revolution of digital technology (digitisation) plays a vital role in the dematerialisation of economy (Ulbrych 2015). Physical goods and services are being gradually replaced by digital versions, and impacts on product innovation, technical upgrading, operational efficiency, and downtime reductions (by means of predictive maintenance and smarter programming of maintenance cycles) were already achieved in many stages of industrial value chains. But these continuing technological developments represent also an important driver of the current and anticipated demanding growth for many CRM, despite the overall tendency to atomisation (i.e., shifting manufacturing models towards additive assembly of very small, custom-designed components). Pressures on the production and availability at affordable costs of these CRM and several other mineral commodities rise considerably when added to the quantities required to meet the growing market demands in technological solutions oriented to (i) electric power generation and reduction of greenhouse gas (GHG) emissions, such as electrical mobility, energy efficiency, renewable energy production and storage; (ii) smart communication grids and advanced interaction tools of widespread use; and (iii) disruptive technologies aiming at increasing levels of automation and efficiency, which may also drive the search for new (smart) materials, including robotics in industrial and residential contexts, autonomous driving, 3D-printing, and drones with specific functions.

To a large extent, many of these transformations, with evident impact in the mining industry and mineral-based value chains, are policy-driven (Tilton et al. 2018). But policy makers must realise that the growing dependence on many mineral commodities should also force significant changes in the current mineral production/supply networks, claiming for an increase of domestic production quotas whenever possible. Without these changes, several difficulties recently experienced as a result of export restrictions, hegemony, and market control by some players will tend to worsen, reinforcing the raising of concerns on security, availability, and costs of minerals and their derivatives (OECD 2010, 2014; UNEP 2016a; Mitra 2019). This could put at risk successful paths towards the goals of many international agreements, namely those concerned with social and economic inequalities and global climate change. On the contrary, if the right political measures were taken, new opportunities will be provided to encourage mineral exploration and develop modern mining centres operating sustainably in countries where these activities were significantly reduced in the last decades, as in the EU.

The existent policy instruments used to promote domestic production should be reviewed in some depth and improved. The task is problematic but essential to face the new challenges imposed by the need to regulate the joint management of products derived from primary and secondary resources and address the increasing number of social concerns. In what concerns the first aim, the intended measures should embrace collectively and coherently the activities related to the access and transformation of raw materials regardless of their origin. This will generate an intertwined body of regulatory solutions that improve the governance of material stocks/flows in the economy, boosting as well the collaborative inter-sectoral management of productive activities. In consequence, mineral-based value chains will be gradually restructured through reinforced regional networks geographically scattered. If suitably implemented, this reorganisation can also assist the quickened spread of good industrial practices and transparent trading processes, besides ensuring consumers that materials used in end-products meet environmental, ethical, and other responsible social standards (McLellan et al. 2009; Epstein and Yuthas 2011; OECD 2013; Ali et al. 2017; Wall et al. 2017; Hofmann et al. 2018; Segura-Salazar and Tavares 2018).

The second aim of the envisaged improvements in policy instruments should be contextualised in narratives seeking for higher levels of procedural fairness, legitimacy, and trustworthiness in decision-making processes related to mineral raw materials (Bice et al. 2017; Boutilier 2020). These processes, from the granting of mineral exploration and exploitation rights to the permitting of industrial infrastructures implicated in mineral transformation, should be simple, consistent, transparent, and easily scrutinised. The proficiency of applicants should be subjected to highly demanding criteria and procedures often involved in rent-seeking and regulatory capture should be changed to correct distorted outcomes (Dumbrell et al. 2020). An open and systematically updated information database about ongoing or planned industrial activities should be created by competent authorities and duly disclosed to the public in general, stimulating further communication/discussion frameworks with a wide spectrum of stakeholders. This will minimise the polarisation of public opinion caused by biased interpretations or conjectures and allow to anticipate potential conflicts at local scales. The scope of evidence-informed decisions should be widened by including sources of knowledge other than technical, legal, or other kinds of expertise (Rifkin 1994; Head 2010; Dumbrell et al. 2020). The means by which minerals are accessed and how these practices are reconciled with other land uses or natural resources/eco-services should also be clarified and balanced.

In this work, some fundamentals on global and regional mineral-based value chains are revisited, commenting their connections with the mining and product life cycles, as well as the need to reorient current procedures to better assist the raw materials demand and supply balances imposed by the main technological and societal drivers. These issues have been recurrently addressed in recent literature, although not delivering an integrative perspective, and to the best of our knowledge, not discussing the importance of have strong regional networks supporting the supply of mineral raw materials located in diverse regions/countries. So, the main goal is to propose a conceptual rearrangement of interconnections between the Mining and Product Life Cycles, leading to the build-up of restructured and more resilient mineral-based value chains that may assist the fundamental drivers of the intended technological and socio-economic development. In this context, the specific case of the EU is analysed, considering the impacts of a reinforced upstream industry (mining/quarrying and mineral processing) in a renewed European raw materials economic sector. Policies that encourage the growth of domestic production of minerals and their derivatives from primary resources in the EU will face strong social disapproval, as documented for many recent situations in different Member-States. Therefore, several additional comments on the relevance of "Corporate Social Responsibility" and "Social Licence to Operate" concepts for public opinion are provided along with suggestions of improved communication approaches to enhance the transparency and accountability of decisions that affect the management of natural capitals of communal use and of public importance, such as mineral resources.

Restructuring global mineral-based value chains

The value chain model (Porter 1985) was originally based on the assumption that partition of business operations into strategically important activities could lead to significant improvements in economic and competitive performances of a particular industrial sector operating in a given region/country. Accordingly, the value chain was conceptualised as a sequential array of functions and links of progressive specialisation, each of which generating an incremental added value. Also, the associated value chain analysis was envisaged as a managerial process designed to evaluate the possibilities of increasing revenue and reducing costs all along that chain and not just in the upstream production/manufacturing processes.

The simple but effective perspective behind Porter's model steadily evolved from vertically integrated economic activities distributed across somewhat limited networks to an optimised productive system spatially scattered in various regions/countries. During this evolution, and seeking opportunities to reduce costs and raise productivity, companies operating in advanced economies moved gradually their manufacturing activities: starting with those requiring high labour input and low technical sophistication, but later on dislocating also specialised segments of the production chains. Therefore, the grid of interdependencies and connections of activities performed within a single company or issued to various companies became increasingly broaden and often of complex governance. At once, many activities were dispersed in places subjected to different legal codes and presenting distinct stages of technological development. The expansion of these practices led to the proliferation of global value chains along with economic globalisation, which transformed quickly the way goods and products are being designed, manufactured, traded, distributed, and consumed worldwide (e.g. Reuter et al. 2010; Parmigiani et al. 2011; Ulbrych 2015).

The paths towards global value chains were triggered and/or facilitated by a long series of notable changes that occurred concurrently, namely those related to incessant improvements in information and communication technologies, trade liberalisation, reduction of transport costs and automation of production. However, the increasing fragmentation of production across various countries, together with tendencies to extreme specialisation in tasks and business functions rather than specific products, has been creating several tensions between different components of the global networks (Kaplinsky 2000; Buckley et al. 2019). This emphasises the need to evaluate the relative contribution of each component to value creation, improving the balance of incomes from standardised and specialised activities included in producer- and buyer-driven chains that form the production and distribution systems created by vertically integrated transnational manufacturers (Mudambi 2008, 2013).

Impacts related to improvements in the (re)distribution of incomes could be tremendous because it promotes new forms of accessing markets, spreading the value-added, technology, and competent regional networks. Furthermore, it stimulates competitiveness and continuous upgrading because evolving/

small-scale companies strive to develop capabilities for value-added activities whereas advanced/large-scale companies tend to dissociate and relocate standardised activities in emerging economies; and innovation generates new activities that despecialise and displace old manufacturing practices. But is it really that easy to disaggregate the value created across the various networks of suppliers, manufacturers, distributors, and associated services to each global value chain? And, considering the technological development achieved in most industrial sectors, is it still valid to classify the activities simply as standardised or specialised? Last but not the least, does this approach actually resolve the socio-economic asymmetries recognised worldwide, as well as the trend towards the hegemony of some companies and/or countries in key production chains? Recent global crises have shown that the over-reliance on a limited number of producers or manufacturers creates increased difficulties in implementing quick solutions to unanticipated problems, as well as in promoting development policies in line with the Sustainability aims. Consequently, should the domestic or regional networks of production/manufacturing be reinforced to ensure some kind of "strategic autonomy"?

Value-driving outcomes provided by the mineral raw material industry

The mining industry has always represented a key set of economic activities with high social impact, serving today as never before a large number of manufacturing chains of goods that are indispensable to technological progress and wellbeing benchmarks (McLellan et al. 2009; Sverdrup and Ragnasdóttir 2014; McHenry et al. 2017; Katz and Pietrobelli 2018; Humphreys 2019). The need for minerals and metals will remain high in the coming decades despite recent efforts to dematerialise the economy and increase the recycling rates of discarded end-of-life products and of residues resulting from mineral exploitation and processing activities (e.g. OECD 2019). Therefore, any changes in the structure or functionality of components forming the global value chains related to mineral raw materials have potential to affect significantly the current patterns of social-economic development, further challenging many paths of the ongoing technological (r)evolution.

A close inspection of relationships that regulate networks of primary minerals production is of prime importance, particularly when connections with downstream chains of material transformation, manufacturing, recycling, and reuse are also considered. These networks and downstream chains complement each other to a great extent, supporting two fundamental cycles that regulate the material flows within the anthropogenic system and across its interfaces with the environment (Fig. 1): the Mining Life Cycle (MLC) and the Product Life Cycle (PLC). A tight and improved connection between MLC and PLC is necessary to ensure affordable costs and acceptable levels of secure supply of minerals, metals and other raw materials required for the anticipated increasing demands related to basic needs and the forthcoming stages of digitisation, energy production/storage and electrical mobility, along with reductions in GHG emissions. The main steps towards an effective economy dematerialisation and decarbonisation rely on transformations in production chains, seeking for improved procedures to operate sustainably.

Exploitation (mining and quarrying) and mineral processing activities play a central role in the internationally joined-up production that collects the material inputs derived from primary sources. These activities take place where mineral deposits exist and, therefore, their delocalisation is physically impossible. Despite the routine of some operations, modern exploitation and processing practices conducted in competitive companies could not be simply classified as standardised, i.e. low value-adding commoditised activities that can be assigned to companies using limited knowledge-based resources. On the contrary, they are increasingly demanding specialised activities that involve a varied and high-qualified workforce, making use of advanced (at times cutting-edge) technologies, regardless of the company size (e.g. Basu and Kumar 2004; Batterham 2013; Lèbre and Corder 2015; Batterham 2017; Ghassim and Foss 2018; Mateus and Martins 2019a). But the effectiveness of these activities depend on previous identification of the mineral resource and a thorough demonstration of its feasible exploitation, which once more include a wide range of specialised activities carried out under the scope of successful, knowledge-driven, mineral exploration surveys (Mateus and Martins 2019a and references therein).

Some nodes of various local or regional production networks include small and medium enterprises (SME) that still use low value-adding standardised practices. Most of these SMEs deal with construction and building materials (including ornamental stones) and have been losing market shares at an increasing rate only reversed when they manage to evolve technologically by themselves or as part of clusters oriented to higher levels of competitiveness, gathering investment capacity in design, advanced manufacturing, and marketing. Other nuclei of artisanal production that still subsist in various regions of the world are also exceptions to specialised activities and governance models that characterise modern mining networks supplying the global value chains. However, the current contribution of these nuclei to global production is minor and tends to disappear as adequate measures to settle social and environmental concerns become implemented.

The need to reinforce the links between mining and product life cycles

Following the market trends imposed by the rise of economic globalisation over the past two decades, the main mining

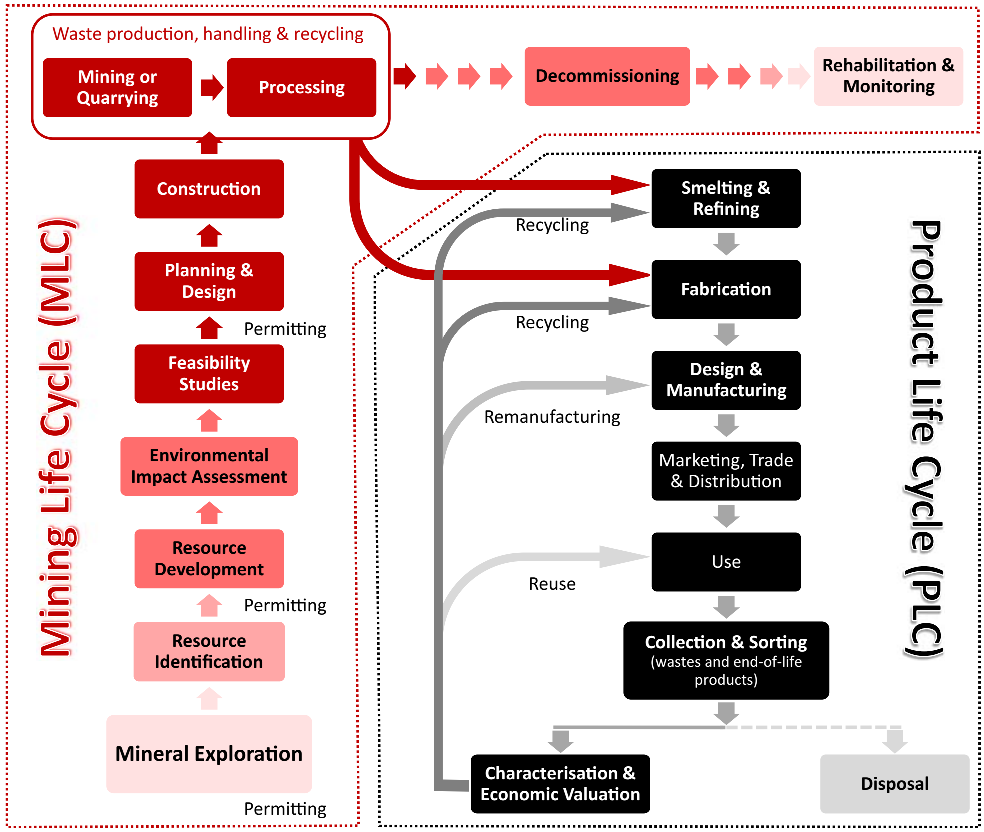

Fig. 1 Schematic representation of the Mining Life Cycle (MLC) and Product Life Cycle (PLC), and their main interconnections. Modified after Azapagic (2004), Durucan et al. (2006), McLellan et al. (2009), Fleury and Davies (2012), Kogel (2015), and Segura-Salazar and Tavares (2018).

networks have significantly reduced their geographic dispersion. Concurrently, the large mining companies strengthened their position in the global market, with several important changes in the industrial structure also taken place worldwide. As a result of these changes, the number of producing countries and relevant companies has dropped considerably, leading to a strong hegemonic tendency in the supply of a large number of mineral commodities. During the same period, and excluding part of the 2004–2012 time range that overlapped the most recent mineral commodities boom, investments in mineral exploration also decreased notably and the number of new 1st class discoveries fall down sharply (Mudd and Jowitt 2018; Schodde 2010, 2014, 2017a, b, c). Together, all these trends have created uncertainties and different types of pressure on the global production networks, which are quite vulnerable to market conditions (namely to price volatility) and geopolitical instabilities (Henderson et al. 2002; Achzet and Helbig 2013; Prior et al. 2012; Habib et al. 2016). Accordingly, well-founded concerns about supply shortages for a large number of mineral commodities have increased, in particular for those that are not easy to substitute and cannot be provided in enough amounts via current recycling procedures.

Some concerns on supply shortages could be mitigated with technological updating and optimisation of production processes in several large-scale mining centres. Indeed, it is important to reduce the average time needed to implement new technology and breakthrough innovations in the mining industry (e.g. Mateus and Martins 2019a; Litvinenko 2020; Gruenhagen and Parker 2020). Often, this takes more than 10 years and became only effective when: (i) seen as critical for new resources development or major expansions of existing facilities, improving the net present value; (ii) perceived as strategic for the long-term aims of the company, reducing the operational risks and/or boosting its competitiveness; and (iii) the cash flow and resources available are sufficient for more than one business cycle. But the acceleration of technological improvements will always represent a circumstantial solution for the security of mineral supply in the future. To be really effective, these improvements should be coupled with significant increases in mineral exploration (Tilton 1996; Petrie et al. 2007; Dubiński 2013; Pokhrel and Dubey 2013) and robust connections with the downstream chains of material transformation, manufacturing, recycling, and reuse.

Fundamental links between MLC and PLC are centred in smelting/refining and fabrication activities (Fig. 1). In both cases, there is an evident value added increasing in comparison with products generated by the upstream mining activities. Companies involved in smelting/refining and fabrication activities act also as privileged bridges with the most relevant players in downstream chains assigned to the design and manufacture of goods and products with even greater value-added. This represented always a major advantage for keeping smelting/refining and fabrication activities close to the specialised and sophisticated manufacturing industries. In addition, as clearly documented in many economies (e.g. Inklaar et al. 2008; Liang et al. 2016; Tsekeris 2017), manufacturing is a key driver of productivity growth that generates also a large number of associated services besides externalities in technology progress, skills development, and advanced learning.

Preservation of the main PLC circuits and related multi-tier proficiencies in the same geographical space create adequate conditions to enhance major rises in the value-added chain, as well as mutual developments vital to continuous revitalisation and achievement of higher levels of competitiveness (Fleury and Davies 2012; Mena et al. 2013; Tachizawa and Wong 2014; Wilhelm et al. 2016). For that reason these industrial clusters were kept mostly associated with advanced economies, favouring a gradual retraction of interests in activities related to MLC, which were basically forwarded to abroad taking advantage of the economic globalisation movement. However, with the growth of environmental concerns in many societies (like in the EU), some of these industrial clusters were partly decommissioned and replaced by an increasingly complex network of services, boosting the dislocation of several relevant heavy industry chains to emerging economies. This accelerated the deindustrialisation of several developed countries (e.g. Nickell et al. 2008; Tregenna 2009; Boulhol and Fontagne 2006; Ulbrych 2015) while creating the idea in public opinion that it was possible to dematerialise the economy quickly.

Dematerialisation, delocalisation, and deindustrialisation of economies: implications to the mineral raw material industry

Dematerialisation of the economy should not be misinterpreted as replacement of products for services. Products will always have to be manufactured somewhere and the materials used in their assembling mined or recovered by recycling or remanufacturing. Dematerialisation refers to the reduction in weight of the materials used in industry and in product design, which can be accomplished mostly via digitisation and atomisation. These processes complement other measures aiming at efficiency improvements in the amount of materials used by society, therefore contributing to the demand/supply balance of minerals exploited in primary resources. Incorporation of recycled materials into smelting/refining and fabrication activities, the growth of remanufacturing rates, the widening of obsolescence cycles of products, and incentives for consumption reduction are major guidelines towards sustainable management of material flows in the economy (Bastida 2014; Graedel et al. 2015a; McCarthy and Börkey 2018; McCarthy et al. 2018; Mateus and Martins 2019a). All these are included in, or directly related to, PLC, but their contributions do not exclude or reduce the importance of inputs from the MLC. The major challenge is the continuous search for the adequate material mix supplied by primary and secondary sources that can support the current and foreseen needs (UNEP 2010a, 2011, 2013b, 2014; OECD 2019; EU Commission 2020a).

Delocalisation and deindustrialisation define the processes of migration and regression of industrial production, respectively. The benefits for large-scale companies, relocating their businesses, and fragmenting their production across countries offering the best conditions to reduce costs, are obvious. But from the point of view of developed countries, this process has been generating an over-reliance on imports of a large number of essential goods (many of which could be manufactured domestically), significant disinvestment and job losses, besides long-term competence deficits. It is argued that a decline in gross value-added generation by industry could be largely compensated by revenues provided by services, as recorded in the last two decades both globally and regionally (Ulbrych 2015 and references therein). However, during the same period of time, it is no less true that the asymmetries of economic development have increased worldwide, causing permanent tensions and promoting social inequities that will persist. In addition, service-based economies have revealed greater vulnerabilities and less resilience in recovering from circumstantial crises.

Some measures are needed to mitigate or overcome the difficulties triggered by extreme fragmentation and delocalisation of productive chains, fulfilling many of the Sustainable Development Goals defined by the United Nations (Wennersten and Qie 2018). These include the reindustrialisation of some advanced economies (such as the EU), along with the international support to both value added increasing in production chains located in emerging economies and restructuring of the fragile economic networks in under-developed countries. Additional efforts should also be done to improve coordination in globalisation and regionalisation processes, boosting or restructuring many manufacturing activities to improve their efficiencies and reduce the reliance on outsourcing and offshoring operations.

Contributions from the mining industry for these endeavours are of utmost importance (Petrie et al. 2007). In fact, being irreplaceable as a raw material supplier from primary sources, this industry has the capacity to redressing some of the imbalances between developed countries and those wherein a large part of minerals exploitation and processing took place (Christmann 2018; Ericsson and Löf 2019; Kaplinsky 2000). Other major achievements can also be carried out by the mining industry if it manages to recover the trust levels meanwhile weakened in some societies, namely through: (i) the right selection of projects and technologies for MLC development with due regard to sustainability goals; (ii) the optimisation of existent exploration and exploitation activities to better assist the demand/supply balance, according to an integrated MLC/PLC outlook and the main drivers of mineral raw materials demand; (iii) the search of adequate communication approaches to improve the transparency and accountability of decisions that affect the management of common natural goods, such as mineral resources; and (iv) the survey of new strategies to improve the engagement of local communities and the society in general into collaborative actions. Indeed, as emphasised in various studies (Petrie 2007; Petrie et al. 2007; Moran and Kunz 2014), the role of modern mining industry operating sustainably could be improved and, above all, better understood and accepted by society, if its activities were rightly recognised and evaluated, from high-level strategic planning to tactical (design-type) situations, through operational practices.

Relevance of regional inputs to global mineral-based supply chains

Globalisation shaped an unprecedented interconnection of economic activities carried out in very different regions often displaying distinct environmental, social, and political backgrounds. Therefore, for each value chain, the identification of central sectors and their vital links is of prime importance to deal with potential disturbances triggered by propagation shocks across the whole network when some major problem occurs in essential nodes (e.g. Kleindorfer and Saad 2005). In what concerns mineral-based value chains, activities placed at the upstream of MLC and PLC represent the most central sectors of the global network.

Significant changes in the supply of non-transformed minerals, affecting the available quantity and/or the expected quality standards and/or trading prices, will impact smelting/refining or fabrication activities with direct repercussions in downstream manufacturing chains. Similarly, technological upgrades or alterations in the number and spatial distribution of industrial facilities implicated in smelting/refining or fabrication processes, will determine adjustments in quantity and/or compositional requirements for MLC-derived flows and their prices, influencing as well the rates with which materials ready to use by the manufacturing chains will be produced. In both cases, the location is important, controlling the framework conditions (environmental, social, and legal) for regular development of activities, in addition to affordable energy and safe/fast transportation routes. In both cases, the required technological support and specialised personnel will have to be mobilised for that specific location whenever needed. However, the decisive factor of MLC activities is the prior identification of the mineral resource that can be exploited profitably; without this identification, none of the remaining activities can be undertaken even in presence of highly favourable contexts. On the contrary, essential PLC infrastructures can be relocated providing that some competitive advantage is envisaged; investments can be compensated in an acceptable time and/or if strategic incentives justify the decision. For these reasons, MLC-related activities are seen as the "most risky and vulnerable links" of the global mineral-based chain, being entirely dependent on the stability of local factors (including reliable and foreseeable regulatory frameworks) and directly exposed to price volatility in the international markets of mineral commodities.

The role of integrated, regional-based MLC- and PLC-related activities

The global mineral-based value chain cannot be sustained for long if production in relevant mining/quarrying operations were subjected to sudden cutbacks or gradual but protracted reductions. This is true for almost all mineral raw materials as demand growth rates far exceed those typifying the increase of inputs from circular material flows provided by recycling and remanufacturing, whenever these are viable. But to ensure a relative stable supply from mining/quarrying operations in time, investments in mineral exploration and in new exploitation centres should not be discontinued, reinforcing the key importance of all the activities covered by MLC, without exception. Accordingly, regional-based networks integrating as much as possible all the activities in MLC and PLC represent the best way to mitigate the extreme fragmentation of mineral raw material production, as well as disturbances that may affect the regular supply of manufacturing chains. These networks should not be confined to a single country. On the contrary, their configuration must rely on input-output linkages between industries of different sizes distributed across neighbouring countries, taking advantage of each contribution to a collaborative endeavour.

The appeal for regional-based development strategies on mineral raw materials is not confined to the creation of a specific demand base or to the benefit of reducing transportation costs and related GHG emissions, although both of them are important variables in the equation (Moran et al. 2014; Odell et al. 2018). The logic of regional industrialisation (or re-industrialisation) and joint industrial policy, comes also from the legacy of regional trade agreements and existing transnational corporation production networks (Mueller et al. 2009; Seuring 2013). Therefore, the expected industrial upgrading focused on MLC-PLC symbiosis will speed up technological dissemination and the corresponding development of skills and employments, ensuring as well a proportional distribution of the value added and a reduction of current socio-economic asymmetries. This regional cooperation will increase the investment capacity, providing the means for improvements in the value chain aiming at higher efficiency and lower environmental impacts, without disregard the support of knowledge-driven mineral exploration surveys and the chances of new discoveries. Concomitantly, the access to higher amounts of minerals from primary resources and of materials from secondary sources will be favoured, expanding the production rates and the opportunity of growing shares in larger markets. If successful, the integration of MLC-PLC activities in different regions worldwide will slow down the overwhelming hegemony of some companies and/or countries in key production chains, quite strengthened in the last fifteen years.

The emphasis on the need to maintain mining/quarrying activities, or to restart them in regions where they were discontinued in the past decades, always raises concerns about environmental impacts, loss of wellbeing by local communities, and potential negative effects on other business sectors, such as indigenous economic activities or tourism. The intensity of environmental impacts is always site-specific and dependent on the methods used in mineral exploitation/processing, thus being significantly reduced when industrial operations are suitably planned and conducted (Hirons et al. 2014; Levesque et al. 2014; Edraki et al. 2014; Giurco et al. 2014; Northey et al. 2017; Ihle and Kracht 2018; Garbarino et al. 2018, 2020; Tost et al. 2018). Communities can benefit from resource extraction in many different ways and this should not be realised as minimum returns in consequence of a harmful inevitability or a curse (Mehlum et al. 2006; Scherer and Palazzo 2011; Robinson et al. 2014; Rotter et al. 2014; Ericsson and Löf 2019).

As stated in Porter and Kramer (2011), the increase of local participation in the supply chain directly supporting the mining/quarrying activities generates societal value and boosts the benefits coming from resource extraction (Xing et al. 2017). This implies however a thorough assessment of the local productivity and corresponding value added to better incorporate the supportive industry clusters near the place where mineral exploitation/processing occurs. If well-succeeded, the assessment will maximise local procurement through strategic supply chain management, i.e. via reinforcements of local economy and respective valences.

MLC- and PLC-related activities in the EU

Mineral raw materials are crucial components of the industrial base still preserved in the EU, which is responsible for the production of a wide range of goods with different technological sophistication levels used in daily routines or in cutting-edge applications. Since the financial 2008–2009 crisis, the manufacturing value added (% GDP) in the EU recovered slightly from 13.24% in 2009 to 14.03% in 2018, still below the 15% achieved in 2007 (https://data.worldbank.org/indicator/NV.IND.MANF.ZS?locations=EU). For this time interval, and according to the same source of data, the industry (including construction) value added decreased from 22.16% in 2009 to 21.69%, continuing the gradual declining imposed by economy deindustrialisation (from 25.17 to 23.77 % GDP in the 2000–2007 period). Yet, the industry directly involved in the production and transformation of mineral raw materials generated a value added of about € 206 billion and more than 3.4 million jobs in 2014 (EU Commission 2018b; OECD 2019). This industry has also been responsible for ≈ 40% of the value added associated with the downstream manufacturing sector in the last decade (EU Commission 2018b), which employs circa 29 millions of workers and is a net exporter of goods (€1,745 billion in 2017). In addition, the globally competitive industrial chains specialised in technology and equipment to mining operations and mineral processing/transformation (from innovative design to assembling, repairing, and recycling) contribute to a wealth creation of € 103 billion, engaging ≈ 2.2 million job positions (EU Commission 2018b).

The EU is self-sufficient in construction materials but the reliance on imports for a large number of mineral commodities is too high, including many of those involved in high-tech applications (EU Commission 2018a, 2020a, b). The existing smelting/refining facilities produce yearly ≈ 45–50 million tonnes of steel and some metals (mainly Cr, Cu, Pb, Zn, and Ag), about a fifth of global production. Nonetheless, most of the ores smelted/refined are imported and the recycled scrap represented no more than 40 to 60% of the annual inputs used in these facilities. Recycling rates of materials consumed in building or automotive applications are remarkable (up to 90–95%), although quite variable across Member-States; on the contrary, the recycled electronic wastes did not exceed 35% to date (BIO by Deloitte 2015; Delloite Sustainability et al. 2017). These figures are far from being enough to meet the demand of operative manufacturing chains, and so, high amounts of refined metals, processed metal compounds, and alloys, as well as intermediate and end-products, are imported every year (above 25 million tonnes per year in recent times; EU Commission 2018b).

In short, the EU is a significant net importer of ores along with a large diversity of metals and other mineral-derived products which makes its economy quite vulnerable to supply disruptions or other market fluctuations impacting the global supply chain for mineral raw materials. Ultimately, persistent shortages in supply represent serious bottlenecks to various economic activities running in the EU, jeopardising a significant number of jobs and many lines of the political agenda for the intended sustainable development. To deal with this sensitive issue, the EU has been privileging trade negotiations and strategic agreements with resource-rich and producer-leading countries, instead of encouraging the growth of domestic production. As a result, the imbalance between the three pillars of the Raw Materials Initiative, launched by the European Commission in 2008, heightened considerably.

Mining in the EU

The mining industry in Europe is declining and losing its influence worldwide, from ≈ 40% of the global mining output at the beginning of the last century to the current share of ≈ 2–3% (Crowson 1996; BRGM 2008; Nurmi and Molnár 2014).

Relevant active mines are few in number and located just in some Member-States (Austria, Finland, Greece, Ireland, Poland, Portugal, Spain, and Sweden). But should these figures reflect limitations imposed by the geological endowment of the EU territory? Or, are they related to other kinds of constraints?

The available information (e.g. Cassard et al. 2015) shows that the European territory is well-endowed with mineral resources, although poorly investigated. In contrast, most of the Member-States display poor levels of attractiveness for the development of MLC-related activities. Using the "Policy Perception Index" of the Fraser Institute (Stedman and Green 2018) as an example, the top five jurisdictions include Ireland, Sweden, and Finland; Portugal, Spain, and Poland are ranked in the top thirty, and the other Member-States are positioned much lower in the ranking. This explains why intensive mineral exploration surveys were increasingly focused on a small number of regions and, concurrently, why the geological attributes up until 1000 m below the topographic surface remain unknown in a large extent of the EU territory.

Changing the current situation in the EU is not easy, but something will have to be done to reduce the persistent uncertainty regarding the future supply of minerals to the European economy. So the main dilemma is as follows: do Member-States find a way around the limiting political and social issues and promote investments locally, or do they invest in resources coming from abroad, reducing the likelihood of supply shortages due to failures of political or trading agreements? Assuming that the main interest resides in internal investments, a reliable and foreseeable regulatory framework must be created to promote all the MLC-related activities, starting with mineral exploration. In addition, the land use planning in each Member-State should consider consistent criteria to safeguarding the current and future access to known mineral resources or promising prospects (Hilson 2002; Mateus et al. 2017; Lopes et al. 2018; Carvalho et al. 2018). The endeavour is ambitious but feasible in an acceptable time period, providing that a coherent plan exists on how to benefit from an integrated transformation of the existing MLC-PLC connections at the EU scale, while creating a robust regional mineral-based value chain.

A robust mineral-based value chain in the EU

The intended mineral-based value chain for the EU should comply with alterations caused by accelerated transitions towards digitisation, automation, and a low-carbon economy. It should also integrate coherently MLC- and PLC-related activities, products, and processes all along the value chain to end-consumer markets, and subsequent management of wastes and end-of-life products. And it has to consider the existing know-how and infrastructures to gradually implement a viable programme of readjustment driven by the main societal demands and concerns, already considered in the EU political agenda (EU Commission 2011, 2014a, 2019; Zils 2016; Hagelüken et al. 2016). As schematically illustrated in Fig. 2 this is a quite challenging programme that imposes increasing levels of responsibility and collaboration between all the players, from companies involved in MLC and PLC to state and public authorities, and the society in general. The foremost aims of this common effort could be organised into five categories, rearranging and updating the scheme reported in Faure-Schuyer et al. (2018): (i) social welfare and equity; (ii) transparent and stable governance; (iii) methodical monitoring of material fluxes and their sources; (iv) regular surveying of energy intensity and sustainable energy power systems; and (v) enhancement of innovation capability. These aims are strongly interconnected, as briefly presented in the following subsections.

Social-political acceptance

Structuring of a mineral-based value chain in the EU, supported by strong domestic integration of MLC and PLC activities, requires levels of social commitment quite different from those prevailing nowadays in the European society. Public opinion about these economic activities will have to change, particularly in what concerns mining, shifting constructively the prerogatives conferred by the Social Licence to Operate. But the simple act of change, whatever it may be, raises always doubts and takes time. Therefore, the reluctance to change is an expected attitude that should not be disapproved, requiring instead plausible elucidations on the need to change existing routines.

Recent advances in information and communication technologies have dramatically changed the way and the speed with which factual news or narratives of any kind are disseminated globally and often uncritically received/used. As a result of this change, the shaping of public opinion and subsequent social engagements are increasingly dependent on narratives spread in mass media and social networks, which are ever more decisive in trade-offs behind contracts between businesses and society (Lachapelle et al. 2018; Jartti et al. 2020; Boutilier 2020). Therefore, narratives about the use of mineral resources and opinions of people who have no direct interaction with companies are becoming major determinants of future developments of MLC- and PLC-related activities in the EU and worldwide (Johnston-Billings et al. 2019). That's why getting a social licence to operate can no longer be seen as an interpersonal relationship–building process involving just the communities close to the industrial facility and/or key stakeholders. It must fulfil other prerequisites, namely those embraced in the general concept of social-political acceptance, as defined in Wüstenhagen et al. (2007). To this end, a suitable combination of strong consistency with other

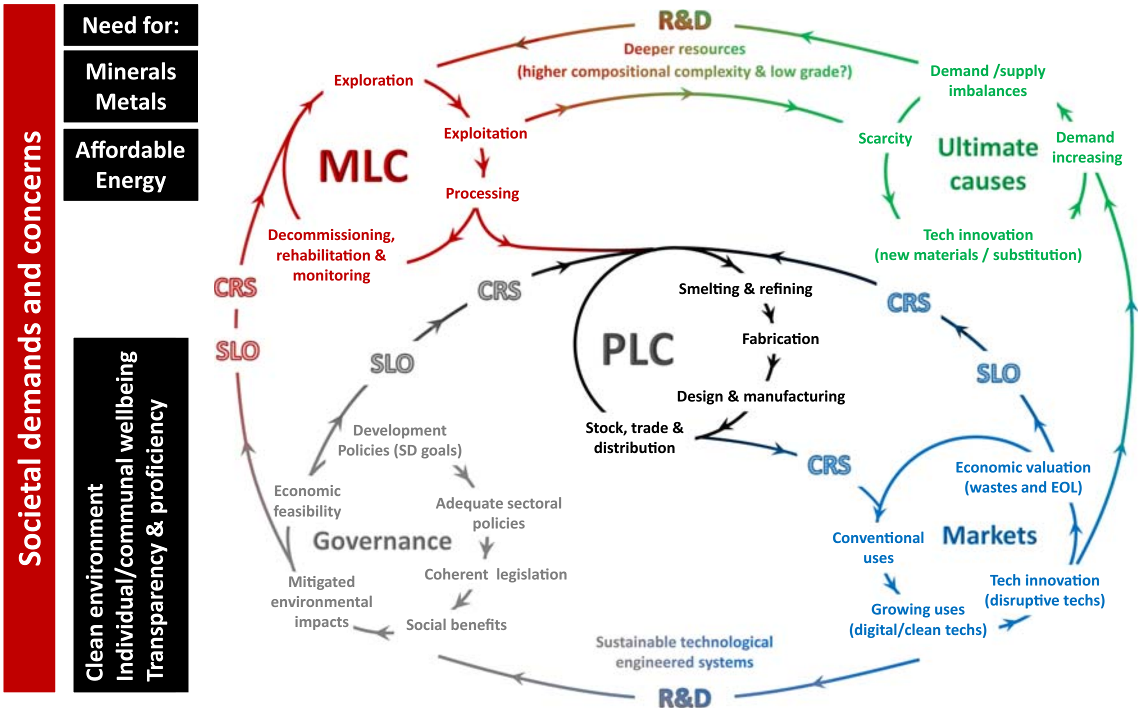

Fig. 2 Main interlinks and flows in a conceptual mineral-based value chain for the EU, integrating the activities, products, and processes related to the mining life cycle (MLC) and product life cycle (PLC) all along the value chain to end-consumer markets and subsequent management of wastes and end-of-life products. The main drivers are: (i) technological advances, supporting accelerated transitions towards digitisation, automation, and low-carbon economy, without disregard the "conventional needs"; (ii) societal, requiring higher fairness and increasing levels of transparency and proficiency from both the authorities and industry players, which should lead to new roles of all interested parts in procedures associated with social licence to operate (SLO) and corporate social responsibility (CSR); and (iii) reliance reduction on imports of ores along with a large diversity of metals and other mineral-derived products which makes the EU economy quite vulnerable to supply disruptions or other market fluctuations impacting the global supply chain for mineral raw materials. The general scheme will promote also a continuous training of a high-qualified workforce and the optimisation of investments in research and development (R&D) in many key sectors of the mineral raw materials value chain.

sectoral policies and well-established agreements in principle should exist, implicating the policy makers and the authorities acting in complementary governance domains, besides the public in general, special groups of interest, and expert organisations.

A key step towards a satisfactory framework of social-political acceptance of MLC- and PLC-related activities in the EU consists on changes how the authorities and companies communicate their plans and decisions, along with a timely spreading of contextualised information. By transforming the traditional communication schemes and in presence of a broad social-political acceptance, it will be possible to minimise the polarisation of public opinion caused by biased interpretations or conjectures, allowing to anticipate suitable solutions for potential conflicts. This issue will be deepened in the next section but, at this point, it is important to clarify that the reasons able to trigger significant changes in public opinion and support the intended social-political acceptance should not be ruled by "business as usual" criteria but, on the contrary, guided by concerns on decarbonisation and optimised material flows in the economy. Concomitantly, it should be shown that the envisaged mineral-based value chain in the EU has a huge potential to consolidate an inclusive social framework based on expertise and employment base, contributing as well to effective territorial cohesion. As a result, the expected spread of skills along with continuously updated knowledge will foster competitiveness and growth. Also, current asymmetries on the level of technological progress across Member-States will tend to decrease and the welfare in less favoured regions should rise through real value-added creation (Alcidi 2019). Furthermore, a robust and responsible mineral-based value chain will strengthen the EU position in some global supply chains and in their multi-tier management. This will facilitate the resolution of social and environmental problems affecting some nodes of international production networks, namely in those operating in regions lacking adequate regulation and/or systematic scrutiny (Locke et al. 2009; Klassen and Vereecke 2012; Hofmann et al. 2018).

Governance system

A necessary precondition for a successful implementation of a mineral-based value chain in the EU relies on the best way to overcome the expected external and internal difficulties in political, financial, and system organisation issues. Thus, consequential policy measures will be needed to better frame the mineral raw materials industry and all associated sectors in the EU, while encouraging stronger domestic connections between MLC- and PLC-related activities and stimulating higher levels of attractiveness for long-term investments.

Changes in current legislation should be implemented, aiming at a consistent, clear, and simple regulatory framework desirably harmonised between all the Member-States, and encouraged by the EU Commission. The envisioned improvements should include the creation of policy instruments able to embrace collectively and coherently the activities related to the access and transformation of raw materials regardless of their primary or secondary origin. Such a reform implies also enhancements in the way economic growth, environmental management and corporate social responsibility (CSR) can be entwined to create a viable sustainable development agenda. However, these administrative changes are not enough *per se*, as the mere existence of mineral deposits or of operational heavy industry facilities does not represent by itself any guarantee of competitive advantage. It will be necessary to gradually reorganise the productive system so that it could assist the purposes of the intended conceptual transformation and react in time to market-driven forces. In this context, a bottom-up reorganisation supported by country-based clusters could facilitate the endeavour, optimising the links between local suppliers of inputs, services, and products, and their net contribution to the MLC-PLC value chains at the EU scale.

To succeed, the mineral-based value chain in the EU should establish its structure in wide collaborative patterns within and across country-based clusters, and commitment measures. Collaborative practices will actively engage and support all the players operating in different tiers of the MLC and PLC structures, reorganising the portfolios of producers/suppliers and manufacturers in the EU. This will ensure a dynamic assembling of materials from primary or secondary sources in the EU, complemented with imports whenever necessary. The commitment-oriented approaches (Locke et al. 2009) will reinforce the links between players acting within MLC and PLC, boosting the collaboration across all stages of the value chain and accelerating the spread of technological innovations. This will generate the conditions needed to achieve high-demanding eco-efficiency levels and improve the development planning for different time periods in each local network supporting MLC and PLC. Concurrently, through this via, continuous training of a high-qualified workforce and the optimisation of R&D investments in MLC and PLC will also be encouraged.

Optimised material flows in economy

Methodical monitoring of material fluxes and their sources represents a central key for the success of the mineral-based value chain in the EU. By means of a regular and continuously updated material flow analysis, it will be possible to assess the material mix that can be provided to the EU economy from domestic/foreigner sources and from primary/secondary resources (BIO by Deloitte 2015). Using stocks of waste and end-of-life products, new innovative solutions can be found to reduce some of the pressure on MLC (Giljum et al. 2014). Even so, these secondary stocks do not represent secure supply sources for the industry, as there are technological and economic limitations to remanufacturing and recycling, here including the difficulties often posed by collection, dismantling, and classification procedures.

Despite the anticipated advances in smart design and life cycle assessment (and inventory) of products and goods, primary ores and refined metals would still be needed to meet the growing demands for digital, disruptive, and clean technologies. So, an increase of domestic inputs from MLC will provide fundamental contributions to the demand/supply balance in the EU, relieving the dependence of its economy on imports of mineral raw materials. The increase of domestic production (in quantity and diversity) from primary resources will not ensure total self-sufficiency, considering the natural attributes of the type of resources that can be accessed in the EU and the foreseen needs, namely those expressed in the most recent CRM lists (Delloite Sustainability et al. 2017; EU Commission 2018a, 2020b). However, some "strategic autonomy" should be possible to accomplish for some ores, refined metals and alloys, and processed metal compounds. This "strategic autonomy" could also be decisive when global supply chains of particular mineral commodities are subjected to the following: (i) market tensions, such as export restrictions and geopolitical instabilities, as recently observed; (ii) temporary shortages, when demand exceeds supply and some delay exists in the adjustment of upstream production; and (iii) structural scarcities, affecting mostly coproducts or byproducts whose supply do not respond necessarily to market demands.

Impacts on the energy sector

Energy intensity (i.e. the ratio between gross energy consumption and GPD) in the EU decreased by 37% between 1990 and 2017 (https://www.eea.europa.eu/data-and-maps/indicators/total-primary-energy-intensity-4/assessment-1). From 1999 to 2005, the economic growth rate exceeded that of energy consumption, reflecting significant efficiency improvements in several sectors of activity. In contrast, the 2005–2014 period was characterised by much lower rates of economic growth coupled with declining in energy consumption. The latter started to increase again after 2014, although not accompanied by similar rates of economic recovery, which could be tentatively correlated with a slowdown in energy-intensive industrial sectors. A straightforward connection between this deceleration and the compliance of GHG emission targets is not clearly supported by the available data. However, it is recognised that there are physical limits for the accomplishment of cost-effective adjustments in many industrial processes so that they can meet the overall restrictions on GHG emissions (e.g. Markandya et al. 2006; Faure-Schuyer et al. 2018; Chang 2014). It is argued in other studies (e.g. Śmiech and Papież 2014) that economic growth occurred recently in some Member-States recording high reduction of GHG emissions and energy intensity, also showing high shares of "renewable inputs" in total energy consumption. Still, this (feeble) economic growth was mostly supported by services, particularly in non-structuring activities such as tourism and related businesses.

Industries supporting the mineral-based value chain are intrinsically energy-intensive and their recrudescence in many regions of the EU will imply regular surveying of the energy intensity and other performance indicators to ensure a balanced and realistic distribution of shares of GHG emissions across all the economic activities. In some cases, as suggested by Faure-Schuyer et al. (2018), PLC-related industries could be relocated to places where alternative energy sources can be provided or where emissions can be captured and stored. Opportunities for symbiosis between different industrial processes could also play an important role in such decisions, combining new market prospects with the challenge to remain cost-competitive.

Policies to meet the EU decarbonisation targets involving energy sustainable systems along with energy efficiency, electric mobility, and other environmental goals, as part of the EU strategy, create additional challenges to industry and society. Efficiency improvements may be enough to achieve short- to mid-term decarbonisation objectives, but to go beyond these transitional steps, considerable and fast transformational changes must occur in electricity systems (namely for heating purposes), mobility (transport), and energy-intensive industrial processes, which together respond to ≈ 4/5 of GHG emissions in the EU. Once again, it will be necessary to look for a portfolio of multiple solutions and think openly because it is impossible to realistically accomplish the EU energy policies without a strong industrial base and a secure access (at affordable costs) to large quantities of a wide range of metals or metallic compounds. The European Battery Alliance, launched in 2017 (https://www.eba250.com/), clearly demonstrates this assertion, although dealing solely with technological solutions aiming at electric mobility and large-scale storage of energy gathered from intermittent sources. In this regard, it should be emphasised that global competitiveness of European industries involved in technologies to generate electric power from energy sources other than hydrocarbons will be strongly favoured in the presence of a succeeded mineral-based value chain operating at the EU scale.

Speeding innovation and technological improvements

Increasing the domestic production of mineral raw materials will stimulate R&D and innovation capability in the EU. Current and foreseen challenges are no longer centred just in competing for the discovery and access to mineral deposits. They also include incessant search for innovative technologies and eco-efficient procedures that, along with new knowledge, may assist advances in MLC- and PLC-related activities, thus optimising the use of primary and secondary sources of materials (Moss et al. 2013; Blagoeva et al. 2016; Ku et al. 2018; Lööw et al. 2019).

Mineral exploration surveys are evolving quickly through the incorporation of updated scientific knowledge and development of various technological tools that facilitate the attainment and joint processing of ever more larger geological, geochemical, and geophysical datasets. Digital technologies and automation, along with custom-designed equipment, are also transforming the production in modern mining centres in conjunction with software-engineered simulations to test cost-efficient solutions during extraction or processing activities, reducing as well the environmental impacts.

Industries at the upstream of PLC are undergoing similar revolutions, changing their operation standards to achieve higher levels of efficiency and respond to demands of manufacturing chains. The need for improvements in recycling and remanufacturing processes, and to produce increasingly complex materials for digital services and disruptive technologies, is also accelerating changes in composition and assemblage of products into intermediate or final goods.

All these transformations have organisational consequences for productive activities across the mineral-based value chain, shaping as well the flows between them. In addition, they have potential to enhance the future scientific and technological capability in the EU, and to promote the development of competences and skills in a varied number of crucial economic activities (World Economic Forum 2016). Altogether, this will generate conditions for the emergence of new business models supported by a reconfiguration of the existing industrial networks that may trigger disruptions of current markets and modify some of the value-added chains.

Social awareness and acceptance of mining in the EU and globally

As aforementioned, MLC-related activities are the "most risky and vulnerable links" of mineral-based chains, being also subjected to strong social scrutiny. Mining conflicts are increasing in number and intensity worldwide, causing additional difficulties to the supply of minerals needed to sustain the ongoing technological (r)evolution. As shown in various studies (Zachrisson and Lindahl 2019; Mercer-Mapstone et al. 2019; Tuulentie et al. 2019), conflicts occur where a significant number of local mining-sceptical individuals mobilise resistance against any kind of activity related to mineral exploration, exploitation or transformation. In many circumstances, the mobilisation gains enough momentum and dimension, generating a broader social movement of difficult stopping. These movements have attained alarming proportions in many regions of the EU, causing interferences in political agendas strong enough to prevent the launch of new promising mining projects and to spread a wrong message about the need of minerals exploitation and the real significance of impacts related to this industrial activity. Comprehensive transdisciplinary studies are needed to better identify the causes, modus operandi and specific intents of these social movements. Nevertheless, the main concerns behind dynamics of structured protests mobilising significant social support can be identified on the basis of information disclosed in media and webpages of various NGOs and/or social organisations purposely created to influence decision-making processes on applications for mineral exploration or exploitation activities.

Common observations show that information about adverse or risky events tend to reach broader audiences, favouring the emergence of biased narratives that often explore fears and uncertainties. The media are well aware of this basic principle and make use of it regularly, regardless of the specific nature of the reported news. By doing so, without offering an appropriate context for particular situations and/or provide evidence on well-succeeded events of similar nature, the media will inevitably shape public opinion about the reputation of those activities and the players involved in their implementation. In the specific case of MLC-related activities, factual reports in non-specialised media on successful mining ventures are rare, preventing the dissemination of technological advances with positive economic, environmental, and social impacts. The need of boosting investments in mineral exploration/exploitation endeavours is also an infrequent topic, even when consecutive studies and press releases from several reputable entities (UNEP, OECD, and World Bank, among many others) leave no doubt about the importance of informing society on that issues. But, when unacceptable incidents occur and real or latent social conflicts emerge, the news are widely spread, often via alarming chronicles. All these journalistic options end up consolidating several subliminal messages that, together, predispose public opinion to the development of a narrative about the current and future irrelevance of MLC-related activities, which are also perceived as a main source of many environmental and social problems.

The adverse narrative about MLC-related activities stimulated by the media and many opinion makers poses significant difficulties in the design of coherent governance policies regarding mineral raw materials and their connections with land use management, public goods, and socially valuable assets. This seriously undermines the mainstays of social-political acceptance required to the building of mineral-based value chains in regions where no historical records exist on these activities or where environmental marks and social recalls of old, faultily conducted, practices are still present. In these circumstances, sectoral authorities and companies promoting MLC-related activities have to make additional efforts to better communicate and justify what they intend to do, how, where, and why. Only then it will be possible to gradually reverse the unfavourable opinion trends and improve the global image of those industrial activities (Mateus 2020), shifting their rating level from "triple-D" (*Dirty*, *Dangerous*, *Difficult*) to "triple-A" (*Accountable*, *Advantageous*, *Advanced*).

Activist groups and social networks amplify the "narrative of irrelevance and environmental/social threat" about MLC-related activities, transforming it into an "anti-mining narrative" where regulations in force are questioned and potential negative impacts are often emphasised on the basis of worst-case scenarios. This generates additional levels of distrust in public opinion and adds further pressure on communities directly implicated in the MLC-related activities. The ways chosen to increase distrust are diverse, but in general, they include suspicion of legitimacy and procedural transparency, besides fears about environmental impacts or misgivings on the real value of promised compensatory measures. Once consolidated, the distrust leads to strong social mobilisation and organised protests. And when answers to the questions are delayed or do not elucidate properly the doubts raised by stakeholders, difficulties in establishing constructive dialogues increase. In such conditions, the legitimate cautious uncertainty of communities gives rise to stances of absolute rejection of MLC-related activities.

Innovative approaches to effective and educated social engagements are among the most challenging issues that the industry has to face (Nelsen 2006; Boutilier 2007). In what concerns mineral exploration and mining development endeavours, perceptible and latent misgivings are usual, ever more replaced by active forms of protest, not always duly substantiated (Hilson 2002; Lemos and Agrawal 2006; Kemp 2010; Bainton and Holcombe 2018; Mancini and Sala 2018). The reputation of mining industry remains tarnished in many countries due to bad examples from the past and perceptions about its contribution to environmental damages and negative impacts on social infrastructures. Such perceptions compel companies to proactively address the subject as a multi-dimensional "risk management" because they are realising that emergent adversities are no more a public-relations problem that can be solved with local communities and their representatives. Changing the message and repairing the adverse image are also insufficient. Additional communication schemes aiming at broader audiences and an enhanced commitment of authorities have to be implemented. Concurrently, other social players than affected communities must be involved in the process, because public opinion is increasingly important in granting the required social-political acceptance (e.g. Wüstenhagen et al. 2007; Johnston-Billings et al. 2019; Dumbrell et al. 2020; Boutilier 2020).

It is therefore crucial to understand why conventional and regulated practices are raising so many suspicions by society. Furthermore, dealing with social misgivings about MLC-related activities, it is also essential to examine the real usefulness of procedures that have been used within the scope of corporate social responsibility (CSR) and in the context of public consultation to obtain the so-called Social Licence to Operate (SLO). The diagram in Fig. 3 illustrates the major links between different elements that often intertwine when this complex issue is addressed. The justification for the favoured path is explained in the following subsections.

Corporate social responsibility and its relationship with social acceptance

The CSR is a broad concept used in different frameworks with various implications such as business ethics, corporate accountability, corporate citizenship, and corporate sustainability. It is a firm-driven policy (Gehman et al. 2016) or a form of self-regulation (Dumbrell et al. 2020) that extends beyond a specific project or activity, generating some ambiguity or even perplexity among people that do not have confidence in industrial activities (Dahlsrud 2008). The original purpose of CSR actions was to provide some kind of social advantage beyond the direct interests of the company and the compliance of its duties imposed by law, which might not necessarily include specific concerns raised by local communities, or the public in general, on ethical or environmental issues. Even so, the CSR commitment of mining companies has evolved gradually since the 1980s to address the multiple expectations of stakeholders, often moving towards issues that hardly fall into the company's direct sphere of influence (Dawkins and Lewis 2003; Detomasi 2008; McWilliams et al. 2006; Lindgreen and Swaen 2010; Scherer and Palazzo 2011). Consequently, the budgets dispended with CSR actions have increased significantly worldwide to expand the scale and scope of initiatives needed to support inclusive development (Kemp et al. 2010; Frederiksen 2018).

Despite the efforts done in recent years, CSR responses to operational, reputational and regulatory/political risks are insufficient or misunderstood by the society, and the reasons behind these difficulties are quite diverse. In some cases, trade-offs between future land uses (or aesthetic values provided by natural systems) and mining developments are no longer considered acceptable or necessary by local communities. In other instances, the willingness to accept some forms of compensation (e.g. access to employment opportunities, upgraded services, and economic growth) exist, but concerns about inequitable experiences of benefits and costs have potential to destabilise the intended contract at any time. Whatever the case may be, the social acceptance will be at risk and conflicts of different nature and magnitude could appear, in particular when a rhetoric based on suspicious feelings prevail over demonstrable arguments.

Quite often, the causes of conflicts are due to unsatisfactory communication between all the players and/or deficient procedural fairness in project's management and/or distinct ways to assess the risks. In many countries, an effective social consultation and a transparent administrative modus operandi are assured, but reluctance levels persist simply because risks are perceived differently. Actually, techno-scientific approaches to the risks involved in a mining project often contrast with social perceptions of those risks, hindering the acceptance of objective solutions to mitigate them or raising doubts about their effectiveness based on straightforward (not always plausible) comparisons with poorly-succeeded examples from the past.

The trust levels to obtain social acceptance require extra care in the way critical information is disclosed by companies and authorities to the public in general, communities, and key stakeholders. The creation by competent authorities of an open and systematically updated information database about ongoing or planned industrial activities is crucial to minimise the polarisation of public opinion triggered by biased interpretations or conjectures. This should be done along with a suitable management of shareholder expectations, thus providing the conditions to ensure a balanced and long-term collaborative governance of the activity (Moffat and Zhang 2014; Dobele et al. 2014). The intended trust levels must cover various items, ensuring as well unquestionable levels of integrity and competence by the companies throughout the mining project lifetime, and yielding a long-lasting social consensus that should support a stable social licence (Joyce and Thomson 2000; Thomson and Boutilier 2011; Prno and Slocombe 2012, 2014; Moffat and Zhang 2014; Morrison 2014; Karakaya and Nuur 2018). Yet, while the attainment and maintenance of a social licence have become matters of strategic importance to companies, discussions on its implementation and real meaning/necessity continue.

Social licence to operate

The SLO is an ambiguous concept (Morrison 2014; Owen and Kemp 2013; Brueckner and Eabrasu 2018) whose clarification is urgent because it allows a wide range of interpretations and actions led by civil society within a largely unregulated "licensing space". Nonetheless, for companies, it is increasingly evident that getting a legal permit from competent authorities and meeting the regulatory requirements is no longer

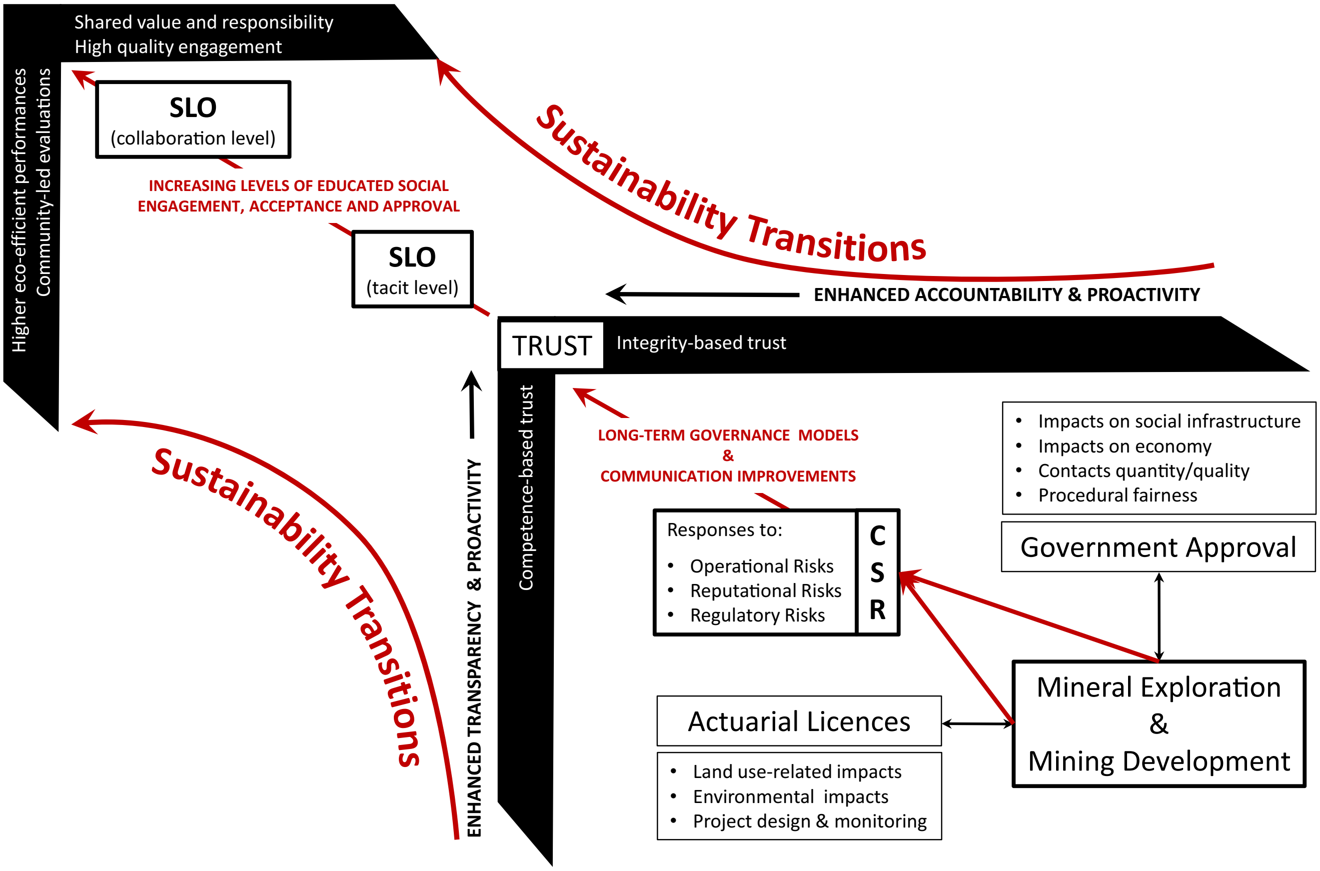

Fig. 3 Conceptual framework that illustrates the favoured perspective about communication with society, and the scrutiny it carries out on activities related to the mining industry. In addition to the requirements imposed by the legal framework, it is increasingly important to consider other issues that go beyond the strict scope of the corporate social responsibility (CSR) and may involve different operational risks, threatening also the reputation of economic players. These issues, broadly included in the social licence to operate (SLO), are still poorly understood by all parties involved in the licensing process, requiring careful analysis to create suitable conditions for the establishment of levels of mutual trust and shared responsibility. Adapted from Mateus and Martins (2019b).

enough; societal expectations must be suitably attended in order to obtain acceptance or approval by communities and the public in general. So, insightful contributions to the management and reconciliation of SLO requirements with regulatory/political and actuarial licences are needed, enlarging the scope of the social-actuarial-political model (Bice et al. 2017), which has the "public interest" as the central focus. In addition, relevant stakeholders and potentially impacted communities vary significantly in terms of size, geography, composition, and education. Therefore, difficulties are expected when the "interaction strategy" is delineated and decided, as different social groups have distinct engagement needs and requirements, being also variably influenced by the public opinion.

To date, SLO has been seen as the social acceptance/approval granted by communities or the public, relying on positive perceptions of legitimacy, credibility, and trustworthiness. Several SLO models have been tested, attempting to integrate the social, legal, economic, and political factors that affect the concept and its governance (Thomson and Boutilier 2011; Prno and Slocombe 2012; Moffat and Zhang 2014; Bice et al. 2017; Dumbrell et al. 2020). The role of public opinion and policy narratives in SLO granting has also been examined in quite recent studies (Lachapelle et al. 2018; Johnston-Billings et al. 2019; Jartti et al. 2020). In line with these results, the "narratives and networks model" reported in Boutilier (2020) seeks for a conceptual integrative perspective, considering the interplay between public opinion narratives and views derived from interpersonal relationships among stakeholders representing communities; in this approach, the social licence is distinguished from its consequences which include legal requirements, economic considerations and social-political factors that could facilitate or obstruct the process. Albeit the significant advances accomplished, we still need a systemic approach to the issue given the broad range of reliant and dynamic variables that can affect the public opinion, community views, and industry development.

Innovative approaches must be tested and validated, improving the methodologies experienced by some limited studies regarding the role of communities and key stakeholders in SLO procedures (Prno and Slocombe 2012, 2014; Moffat and Zhang 2014; Brueckner et al. 2014; Zhang et al. 2018), and the influence of public opinion surveys (Lachapelle et al. 2018; Jartti et al. 2020). Although limited, these studies had the merit of demonstrating that SLO can be more than an intangible and unwritten process (Franks et al. 2013), difficult, if not impossible, to measure (Parsons and Lacey 2012). In this regard, the design of suitable roadmaps (Phall et al. 2004; Saritas and Aylen 2010; Ahmed and Sundaram 2012; Bolboli and Riche 2013; Caritte et al. 2015) oriented to the social acceptance of mineral exploration and mining is promising, particularly if complemented with modern marketing/communication schemes where other stakeholders, especially governmental organisations, should be actively involved. Possible solutions may include:

1. The duly appreciation of public comments, taking them as valid evidence and insight to the decision-making process, alongside with technical, legal, or other expertise contributions (Nguyen et al. 2020);
2. The provision of access and influence of mining-sceptical actors (individuals or organisations) to policy formulation or implementation (Zachrisson and Lindahl 2019);
3. The reinforcement of dense networks of interaction between communities and companies, fostering reciprocity and trust (Suopajärvi et al. 2019) and enhancing collaborative procedures (Devenin 2019; Fraser 2019; Fraser et al. 2019);
4. The closer inspection of coalitions in stakeholder networks acting at different scales and encouraging their capacity to collaborate towards a major socio-political goal (Boutilier 2020); and
5. The establishment of conditions to conceptual evolution of the risk concept (combining techno-scientific with social perspectives) and the corresponding search for the best method to deal with (Kemp et al. 2016).

In our perspective, all the aforementioned possibilities should be viewed as supplemental approaches that need to be properly weighed in a common strategy.

To be succeeded, mining companies should reconsider and convert their routines regarding the ways they communicate, enhancing the transparency and accountability of their actions/results and explaining whenever necessary the rationale behind changes in strategic direction. This represents a key transformation that can no longer be overlooked, contributing also to a well-informed public opinion. Concurrently, the role of (local, regional and national) authorities has to evolve from the administrative conventional procedures of licensing and periodic inspection to a routinely releasing of well-founded information, anticipating the growth of social movements based on fears and guesses. This implies an extension of their good governance procedures to social issues with a twofold objective: (i) supplying the information-driven society with data and other pertinent reasoning on mineral raw materials and (ii) strengthening of continuously open and participative dialogue with communities, enrolling as much as possible the mining-sceptical actors. During the process, a shared vision on progress and wellbeing should be structured, never disregarding that: (i) long-term goals always lead to short-term policies; (ii) social and environmental concerns require dynamic and permanent analyses based on multi-domain, multi-actor, and multi-level approaches; (iii) learning procedures are part of the *modus operandi*, implying a continuous change of experiences between all the stakeholders; (iv) constructive changes of common practices rely usually on cumulative improvements in small intangible issues; and (v) complex problems do not have single solutions, being crucial to keep open all the possible options.

Concluding remarks

Technological innovation has been instrumental in the development of society since the advent of Industrial Revolution, supporting five long periods (waves or super cycles) of economic prosperity separated by global crisis scenarios of variable length and severity, as firstly conceptualised by N. Kondratieff (Perez 2002, 2010; Korotayev et al. 2011; Morone 2016; Grinin et al. 2017). During these five periods of economic growth, industrial activities were able to access primary resources almost without restrictions, which provided abundant and low-cost energy besides the supply of huge amounts of mineral raw materials at affordable prices.

The current situation is transitional from the 5th to the 6th wave, i.e. from a period of economic growth ruled by fast improvements in biotechnology, digital networks, software design, and information and communication technologies to a period where sustainability is the key concept (Ambec et al. 2013; Morone 2016). This implies new ways of perceiving natural resources and of gradual replacement of conventional industrial procedures to access and transform energy and material sources. Therefore, the main drivers for the expected new wave of economic prosperity are technological improvements that allow increases in digitisation, decarbonisation, and dematerialisation. The access to energy and raw materials will become expensive, requiring greater parsimony in their consumption, but significant improvements are expected in technologically sustainable energy systems, nanotechnology, ecodesign, and industrial ecology (i.e., optimisation of material and energy flows through industrial systems). Nonetheless, parsimony in energy and material consumption along with higher levels of energy efficiency and of materials reprocessing does not mean that MLC-related activities could be neglected. On the contrary, primary mineral resources will always represent a critical part of the material flows in the economy and the mining industry will remain as a net provider of value added across economic chains. Worldwide, this industry plays also a central role in redressing some of the imbalances between developed countries and those wherein a large part of mineral exploitation and processing still took place.

With globalisation, trade and production have been increasingly interlinked, thanks to the vertical integration of industrial production processes through outsourcing and offshoring. However, significant changes in international supply chains occurred after the 2008–2009 trade collapse, partly due to the intensification of some main drivers of the 6th wave (Morone 2016; Grinin et al. 2017). In this context, the weight of regional networks in restructured global production/distribution chains for many products and goods has been registering a gradual but significant increase. Similar changes should be expected in supply chains of mineral raw materials, namely for those impacting directly the development of digital, clean, and disruptive technologies of widespread use. As already noted by Faure-Schuyer et al. (2018), the mineral commodity plateau recorded by China since ca. 2004 and its recent (2007–2008) entry into recycling may signal a turning point in global markets, for both supply and production as well as for industrial production.

Currently, the success of manufacturing industries operating in the EU depends on the ability to integrate fragmented production within global circuits. The overall competitiveness of these industries relies on their proficiency and participation in collaborative production networks involving both local/regional production and foreign activities. Smaller companies (SMEs) need to focus on activities and tasks in which they have comparative advantages and search for intermediate components from foreign sources through competitive market-based arrangements. In high-technology industries, however, the reliance on imports of mineral raw materials is too high, raising concerns about future security/stability of supply at affordable costs. The development of a mineral-based value chain in the EU is therefore strategic in both economic and political perspectives, particularly if oriented to a strengthened connection between all the MLC- and PLC-related activities. To this end, a clear regulatory framework and a strong partnership among state and public authorities and private investors will be needed, desirably supported by operational clusters in each Member-State and inspired by the EU Commission. Re-industrialisation policies should be encouraged through a co-industrialisation framework that includes complementary companies across geographic space and not based on the "local vs. foreign" mentality of the past. Concomitantly, public policy should focus both on facilitating exchanges among actors engaged in complementary activities and increasing collaboration among private sectors. This will create various levels of "strategic autonomy" and when domestic production does not meet demand, stable and ethically responsible trade rules, in compliance with the Extractive Industries Transparency Initiative (e.g. Haufler 2010; Aaronson 2011) and the EU Regulation on Conflict Minerals (EU Commission 2014b), must be established for securing access to minerals. The social commitment to this complex but urgent process is critical and the arguments to be used should rely on the necessity of this step-forward to consolidate the position of the EU in the forefront of consequential policies and practices towards sustainable development.

Assessing and improving the sustainability of products and services necessarily requires a life-cycle approach, considering the complete supply chain (from MLC to PLC) and examining the role of consumption as the driver for production. The economic and environmental dimensions can be appraised by means of integrated approaches to value chain analysis and life-cycle assessment to show the distribution of economic benefits and environmental impacts along the supply chain. Environmental intensities (i.e. impact per unit of added value) are frequently high for extraction/processing and smelting/refining activities and reduce gradually along the supply chain through manufacturing and distribution. There are imbalances in many segments of the supply chain, but the most critical could be significantly mitigated by making use of the best cost-effective technical solutions available in each moment. Consideration of social impacts in this kind of assessments will require further methodological development, not only to record the social benefits of activities in the supply chain but also to analyse the relationship between all the relevant players in the supply chain (Prno and Slocombe 2014; Zhang et al. 2018).

In what concerns the social opposition to mainstay MLC- and PLC-related activities, a systematic investigation of the prevalent roadblocks in communication between all the relevant players (companies, authorities, and public in general) must be done. Additional efforts should be completed to address various perspectives of risk (based on techno-scientific approaches and social perceptions), intending an assessment of the real value of the "social acceptability risk" (the mainstay of SLO) for the emerging (and growing) mining-sceptical social movements. Furthermore, the understanding of multi-scale intertwines between components of the "material system" supporting society and appreciation of related benefits, will also be determinant for increasing level awareness and social acceptance of mineral exploration, mining, and mineral processing activities.

It is recognised that the conceptual purposes here advanced have limitations and require more empirical evidence and/or deepened (quantified) analysis. Nonetheless, further research exploring the indicated relationships between MLC- and PLC-related activities, as well as examining possible organisational variations and/or advantages triggered by integrated levels of "strategic autonomy" in mineral raw materials, will enhance the current understanding about the viable options to accomplish a competitive mineral-based value chain in the EU.

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