Towards product-oriented sustainability in the (primary) metal supply sector

Rodrigo A.F. Alvarenga, Jo Dewulf, Jeroen Guinée, Rita Schulze, Pär Weihed, Glenn Bark, Johannes Drielsma

A R T I C L E   I N F O

Keywords:
Raw materials
Mining
Metal
Life cycle
Sustainability

A B S T R A C T

Consideration of sustainable supply of (primary) metals is increasingly influencing the policy agenda of western societies. Environmental sustainability can be managed from different perspectives, including a site-oriented one (strongly used by the mining sector) and a product-oriented one (as with life cycle assessment). The objectives of this article are to analyse and discuss the differences in these perspectives; to discuss potential benefits to the metal/mining sector of also considering the product-oriented perspective; and to propose ways for a smooth implementation. We made use of literature and expert knowledge, on top of interviews with different stakeholders, to identify why and how these perspectives are (not) used in the metal/mining sector. Moreover, we identified three key concerns related to the implementation of a product-oriented perspective in the sector (e.g., use of unrepresentative life cycle inventory (LCI) datasets for metal-based products) and proposed three corrective actions for all of them (e.g., increase the quantity and quality of LCI). Finally, we discuss how the corrective actions could be implemented in the sector in a smooth way and some potential benefits from its implementation.

1. Sustainability of (primary) metals supply

Sustainable management of raw materials (primary and secondary) is now more than ever on the European agenda, with perceived scarcity of metal and mineral resources by some thought leaders, growing demand for metals (Elshkaki et al., 2018), and increasing awareness of environmental and social impacts related to mining operations. The Raw Materials Scoreboard (European Commission, 2016) highlights specific environmental issues throughout the supply chain of raw materials, such as air emissions, water use, extractive and other product-related wastes, and the need for a circular economy.

When focusing on the environmental pillar of sustainability (i.e., environmental sustainability), it is often interpreted and approached from different perspectives, depending on specific goals of a company/organization. For instance, (i) a company or a sector seeks sustainability by implementing programs to reduce the impacts and ensure certain benefits of their activities on the local environment and/or host community. We will call this as a site-oriented perspective. Alternatively, (ii) a company or a sector may seek sustainability by implementing eco-design practices for its products to address impacts throughout their life cycles. We will call this a product-oriented perspective. Other perspectives with a different scope of action are also possible (e.g., environmental compensation at damaged areas, to promote environmental awareness in society, etc.), but are not further discussed in this article. These different perspectives typically involve different actors and lead to different strategies.

Like many other sectors, the mining, smelting and refining sectors (a subgroup of the metal sector) have taken several initiatives to improve their environmental sustainability. Measures typically employed are Environmental and Social Impact Assessment (ESIA), Environmental Management Systems (EMS) (e.g., ISO 14,001) and corporate reporting, e.g., Global Reporting Initiative (GRI), amongst others. Obviously, these actions fit mainly into the first mentioned perspective (i), i.e., a site-oriented perspective.

In the end, the raw materials supplied by the mining, smelting and refining sectors (e.g., copper cathode) are further processed in...
downstream sectors ending up in final goods (e.g., laptop). Increasingly, the final retailer or user of these goods seeks a better understanding and transparency of the environmental sustainability of the products along their life cycles, as indicated by the increasing number of eco-labels, product certification schemes and environmental product declaration (EPD) programs, starting from the 'cradle', in many cases the mine or early exploration stages. This product Life Cycle Thinking (LCT) approach has been widely used and matches with the second (ii) perspective mentioned above, i.e., a product-oriented perspective. Similar to what happened with a site-oriented perspective a few decades ago, product-oriented perspectives are now gaining importance in public policy. In this context, Life Cycle Assessment (LCA) (and/or Life Cycle Sustainability Assessment (LCSA)) is a key method and has become an essential basis for industry in a wide variety of sectors to quantify its environmental performance (e.g. the European Commission's Product Environmental Footprint).

There is not a clear and immediate link between the initiatives taken by the mining/metal sector to satisfy the demands of its stakeholders in the direct vicinity of their site on the one hand (via a site-oriented perspective), and the request by stakeholders downstream in the value chain (e.g., smartphone users) on the other (via a product-oriented perspective). The objective of this article is to analyse and discuss the differences between a site-oriented and a product-oriented approach to sustainability assessment; to discuss potential benefits to also consider the product-oriented perspective within the mining/metal sector; and to propose ways for a smooth implementation.

The next sections of this article are divided in the following structure: Section 2 shortly describes some key aspects of materials and methods; Section 3 describes the current practice of a site-oriented perspective for sustainability management in the mining/metal sector; Section 4 describes a product-oriented perspective and how and why it is implemented in the mining/metal sector; Section 5 discusses the perception of LCA (an operational methodology for a product-oriented perspective) from within the mining/metal sector, highlighting some key concerns; Section 6 makes proposals for moving forward with the key concerns raised in the previous section; and Section 7 are the final remarks.

2. Materials and methods

Based on expert knowledge and literature review, we make a short analysis of how the mining/metal sector currently deals with sustainability (section 3). The analysis is done considering different levels of implementation, i.e., at global level (for the sector), at national level, at corporate level and, finally, at operations/projects level.

In section 4 we make a short description of a product-oriented perspective, LCT and LCA, and analyse a selection of scientific articles related to LCA in the metal/mining sector, again based on expert knowledge and literature review.

Moreover, we bring in this section partial results of 15 interviews during the SUPRIM project with selected stakeholders, i.e., the LCA community, downstream industries (from the mining, smelting and refining sectors) mining/metal industry and associations (Alvarenga et al., 2017), where we identify why there is a demand for LCA studies of the mining/metal sector.

In section 5 we make use of another intermediate result of the survey performed during SUPRIM project, but focused on the four interviewees from the mining/metal industry (Alvarenga et al., 2017), where we were able to identify three concerns directly related to the implementation of a product-oriented perspective in the sector. We propose three corrective actions to address these concerns, based on our collective experience, which are further discussed in more detail in section 6. However, it is important to clarify that these proposed corrective actions are not yet validated in the sector and that they are not an exhaustive list.

3. Current practice in the mining/metal sector

Sustainability assessment in the mining/metal sector can be considered at a number of different scales, i.e., at the scale of individual mining/smelter project or site, at the corporate scale (many mining companies operate more than one site), at the national or regional scale (e.g., the gold-mining sector in Australia or South Africa (Stewart and Petrie, 2006)), or even at the scale of the whole sector globally. These assessments are focused on a site-oriented perspective.

3.1. At global level for the sector

During the 1990s, several multi-national mining and smelting companies became increasingly aware of the need to undertake a global assessment of the sustainability of their operations. This led to a number of sector-wide assessments, including the Global Mining Initiative (IIEC, 2002), the World Bank Extractive Industries Review (World Bank, 2004), and the Whitehorse Mining Initiative (Natural Resources Canada, 1994).

As part of the Global Mining Initiative, the International Institute for Environment and Development proposed a framework for sustainability assessment of individual mining projects that was represented by posing seven questions (Fig. 1). The global assessments were undertaken through extensive stakeholder consultation and typically sought to inform on a similar set of issues or topics related to potential environmental, economic and social impacts of mining (Hodge, 2011; IIEC, 2002). What became known as the Mining, Minerals and Sustainable Development (MMSD) initiative produced 175 research reports and papers from across the globe (ICMM, 2017). The project report, published in 2002, describes the fine balance required for sustainable mining through elaborating on five types of capital that need to be managed: natural, manufactured, human, social and financial (IIEC, 2002; Tilton and Guzman, 2016).

3.2. At national level

Sustainability certification, frameworks, guidelines or standards are now emerging as effective means of self-organisation at national level that can describe the sustainability performance of the mining and primary metals sectors. A common challenge, however, is unlocking sufficient value from such schemes for the mining and metals companies, as opposed to value for national authorities and stakeholders.

The scope of related assessments bridges to some extent to other assessments (previously mentioned). For instance, the Mining Association of Canada’s Towards Sustainable Mining commitment (MAC, 2017) addresses six major themes, including aboriginal and community outreach (Fig. 1).

3.3. At corporate level

In response to the findings of the MMSD, the International Council on Mining Metals (ICMM) established its Sustainable Development Assurance Framework, which refers to ten defining principles and a series of position statements that together provide a basis for assessment of the sustainability of its individual member companies (ICMM, 2017).

ICMM member companies are committed to public reporting of sustainability performance in line with the Global Reporting Initiative (GRI, 2011) and its Mining & Metals Sector Supplement (MMS) (GRI,
From the perspective of producers and consumers of final products, the OECD Multi-National Enterprise Guidelines, National Contact Points and Due Diligence for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas are high profile tools for the assessment and de-risking of supply chains.

Public reporting standards, associated due diligence, independent expert review and assurance, and the Extractive Industries Transparency Initiative (EITI, 2017) are tools used by stakeholders to assess the sustainability of corporate entities in the oil, gas and mining industries.

At operations/projects level

In almost all jurisdictions, the key tool for assessing the sustainability of mining and primary metals production projects is ESIA. In many cases, ESIs are published for comments and will typically be required to contain information on all potential significant impacts, e.g., potential for dust and air pollution (Nelson, 2011).

Guiding tools for ESIA are the Equator Principles (EP, 2017) and the International Finance Corporation’s set of Environmental and Social Performance Standards (IFC, 2017). Sustainability assessment during operation is typically undertaken within a management system based on those described in the International Organization for Standardization (ISO) standards (9000, 14,000 and 26,000 series) and Occupational Health and Safety Assessment (OHSAS) series.

A constant feature throughout the life cycle of a mining project is balancing uncertainty with risk identification and assessment, including risks for investors, stakeholders, operators, workers, host communities, the surrounding environment and host nations. Pre-feasibility and feasibility studies require a range of assessment tools in order to examine aspects to an increasing level of detail and target-level of certainty, e.g., determination of the mineral resource and reserve estimate; market analysis; and quantification of the environmental and socio-economic impacts; amongst others (Bullock, 2011). Assessment tools for these purposes may include preliminary hazard analysis, failure mode and effects analysis for large tailings dams, cause and consequence analyses such as inundation studies, amongst others.

4. A product-oriented perspective

4.1. A product-oriented sustainability assessment, LCT, LCA and LCSA

When considering the environmental sustainability of products, and therefore focusing on a product-oriented perspective, one should consider an LCT approach. The main reasoning is to avoid burden-shifting, i.e., transferring the problem instead of solving the problem. Burden-shifting can happen in different ways, e.g., (a) from one life cycle stage (e.g., production) to another (e.g., use phase); or (b) from one geographical region (e.g., Europe) to another (e.g., Southeast Asia); or (c) from one sustainability issue (e.g., water scarcity or climate change) to another (e.g., gender inequality or acidification) (Finnveden et al., 2009).

A few LCT methodologies have been developed throughout the years, and we will focus in this article on LCA. LCA is a tool to assess the environmental impacts and resources used throughout a product’s life cycle, i.e., from raw material acquisition, via production and use phases, to waste management (ISO, 2006). LCA advanced from energy analysis and environmental burden analysis in the 1970s, to developing more robust impact assessment models in the 1980s and 1990s, and to LCSA including life cycle costing and social-LCA amongst other aspects in the 21st century (Guinée et al., 2011). Nevertheless, life cycle (sustainability) assessment (LCSA) is in constant evolution and several challenges still exist (Finnveden et al., 2009; Guinée et al., 2011), e.g., quantification of spatially-differentiated environmental impacts.

Environmental protection is a fundamental objective in several countries, which is reflected by agreements, policies and laws addressing the three pillars of sustainability (Fig. 1) in different regions/countries, e.g., the European Union (De Camillis and Goralczyk, 2013). In this sense, LCA applications have grown also outside of academia.
For instance, the use of LCA-based EPD is growing in several economic sectors, especially in the construction sector (Passer et al., 2015); and discussion topics of industrial and consultancy interest are popping up in LCA-related conferences, e.g., LCM (2018).

4.2. LCA in the metal sector (mining, smelting and refining)

To date, LCA studies only play a minor role within the mining industry itself (Awuah-Offei and Adekpedjou, 2011; Drielsma, personal communication). However, the demand for life cycle inventory (LCI) data and LCA studies is increasing (Davidson et al., 2016; Greig and Carey, 2016; Santero and Hendry, 2016). There are two main reasons driving LCA studies at mine sites so far (Drielsma, personal communication). The first reason is to support site-based problem solving (e.g., process optimization and investment decisions), thus focusing on impacts which occur at the site and are directly controlled by the company. Hence, they are focused around site-specific operations and do not typically have a focus on final applications (final user product). The second reason is to provide practitioners with LCA data, mainly driven by an increased pressure from market drivers (e.g., building certifications and environmental labels), but also to provide more information of environmental impacts to stakeholders (Greig and Carey, 2016; Van Genderen et al., 2016). The LCI data are typically collected by commodity associations via processors of mining products (e.g., smelters) and published on their websites (e.g., Copper Alliance, 2018). In most cases, data from a mine site is already generated for its own activities, but requires completion and reformating for the purposes of LCA (Mistry, 2018).

A whitepaper published a few years ago gave recommendations on methodological choices for LCA studies (e.g., allocation choices) to assess the environmental impacts of metal products (Santero and Hendry, 2016). A few LCAs performed by the mining and metal industries have been published following these recommendations for different metal products (nickel, manganese, zinc, aluminium, molybdenum, and lead) (Davidson et al., 2016; Hardwick and Outteridge, 2016; Mistry et al., 2016a, b; Nunez and Jones, 2016; Van Genderen et al., 2016; Westfall et al., 2016).

4.3. The demand for LC(S)A in the mining/metal sector

Based on 15 interviews performed with different stakeholders, during SUPRIM project (Alvarenga et al., 2017), we could conclude that the major driver of performing an LC(S)A is the end-user of the study, i.e., to whom it is intended. We describe this in a generic and simplified example, involving the following actors: (A) Society, that can be split in (A.1) civil society, (A.2) policy makers, and (A.3) clients (final consumers); (B) Metal sector value chain, that can be split in (B.1) Mining industry; (B.2) Mining/Metal associations; and (B.3) Downstream industries (metal-based manufacturing industries that are located downstream in the value chain from mining, refining and smelting sectors); and (C) LC(S)A community, that can be split between (C.1) LCI Database suppliers and (C.2) Others (which include LCA software developers, LCA consultants, etc).

In a nutshell, a few downstream industries (B.3) of the metal value chain (e.g., smartphone or automotive manufacturers) have goals to deliver more sustainable products, for several reasons (e.g., green marketing). Usually these goals are set due to pressures received by direct clients (A.3) (or clients of their clients) and/or by policy-makers (A.2) (who will have received pressure from civil society (A.1)). These downstream industries (B.3) propagate this pressure towards mining companies (B.1) and metal producers (B.1), directly or indirectly via associations (e.g., Eurometaux or the European Copper institute) (B.2), and (to a lesser extent) to LCI Database suppliers (e.g., ecoinvent) (C.1), through requests for LCI data (Fig. 2). The propagated pressure, starting from the civil society (A.1), is related to the elaboration of LCI data, also known as ‘eco-profiles’ in some sectors (Plastics Europe, 2018). To respond to these pressures, downstream industries (B.3) often perform sustainability assessment studies, such as LC(S)A; while associations often provide eco-profiles for their commodities (or LCI).

Fig. 2 illustrates the societal pressures as drivers for LC(S)A studies (or other environmental sustainability assessment), next to reasons of economic, competitive or legal nature. However, a few connections between actors in Fig. 2 are malfunctioning (e.g., unrepresentative LCI data in “LCI database suppliers” and inappropriate communication of “Env. Sust. Assessment” studies to society). These can be viewed as opportunities for improvement.

5. Key concerns from mining/metal sector regarding the implementation of a product-oriented perspective

As mentioned in the previous section, the SUPRIM project team performed 15 interviews with selected groups of stakeholders, and in section 5 we focus on the results of four interviews of one stakeholder group (the mining industry), where we highlight some key concerns related directly to LC(S)A. These concerns are, in some way, related to the malfunctioning connections of Fig. 2, mentioned in the previous section.

While four interviews may not be statistically representative, a few aspects allow taking their information with high relevance. First, the persons who provided the interviewee were (sustainability) managers with good experience on the topic. Second, their organizations represent operations in six continents (North America, South America, Europe, Africa, Asia and Oceania), producing several types of minerals and metals (e.g., Copper, Zinc, Silver, Gold, Lead, Aluminium). Third, the key concerns identified by the interviewees were (informally) corroborated by different mining/metal associations (e.g., Euromines) and (some of them) have had already been discussed in different initiatives, such as the Product Environmental Footprint (PEF) pilots.

5.1. Use of unrepresentative LCI Datasets for metal-based products

Several stakeholders mentioned that LCA studies often make use of unrepresentative LCI datasets for metal-based products, mainly regarding background data2. They have mentioned that using outdated datasets can harm the quality of such LC(S)A study. Moreover, current LCI databases sometimes suffer from inconsistency in data quality. To use this data in a meaningful way, LCA practitioners need to have sufficient knowledge about mining and metallurgy; otherwise, there is a risk that LCA results may show unrepresentative (or even, industrially impossible) scenarios.

On the one hand, aggregation of LCI data into average global datasets (as delivered by a few LCI databases and commodity associations) is practical because it represents the real average global data. LCI data collected from one specific operation is simply not representative for a global industry (Swart and Dewulf, 2013), who observed that the energy demand for copper mining can vary between 0.07 and 0.84 MJ eq/kg ore.

On the other hand, when only average global dataset are available, there are none/mains for mining companies to distinguish themselves from individual competitors (e.g., other mining companies), with a different environmental profile. This is mainly due to the lack of a recognized business case for providing the company specific data with which to perform such comparisons. If a business case could be identified, LCA studies could be used as a means to illustrate differences in mining operations concerning environmental impacts, and to support green

---

2 While “foreground data” refers to data that are under the control of the LCA practitioner during an LCA study; “background data” refers to data on which the LCA practitioner has no or (only) indirect control under an LCA study (Life Cycle Initiative, 2018). Therefore, usually “background data” are supported by LCI Datasets.
5.2. Misuse of data in LCA studies and lack of communication

A few stakeholders mentioned problems of misuse of (foreground) data in LCA studies related to mining and metals. An analysis later identified that this misuse of data stemmed from, among other things, inappropriate allocation choices. For instance, one person interviewed in the course of the SUPRIM project mentioned a case in which they provided data from one refinery plant that produced around 15–20 products, where the user of the data allocated all flows to one particular product only, leading to wrong conclusions. Moreover, it was understood that most cases of misuse of data are due to a lack of meaningful interaction between the LCA practitioners and the sector.

5.3. Benefits of materials are not quantified in LC(S)A

A relevant drawback of LC(S)A identified in the interviews is that the societal benefits which the sector brings to society in the form of investments, products and processes are not properly quantified in LC(S)A studies. For instance, it was mentioned that it is difficult for the community to assess and evaluate the positive effects of the mining activity (e.g., job creation) and that a novel and credible model is needed. In other words, a juxtaposition of the burdens created by the producing sector versus the benefits both on-site and downstream in society (due to the activities of the sector) is somehow lacking.

6. Way forward

Based on our collective experience, we propose three corrective actions as a possible response to the key concerns mentioned in Section 5, which can be tackled in a cost-efficient way (below). More detailed thinking about these corrective actions and their implementation is provided in the subsequent subsections, where we anticipate how they may be implemented and how they could support solving the key concerns.

- Increase the quantity and quality of LCI data;
- Incentivize the collaborative work between different scientific communities;
- Better objectivation of the benefits downstream of the sector;

To support an understanding of which corrective actions can tackle which concern (and indirectly support other corrective actions), we provide a schematic overview (Fig. 3). The suggested corrective actions should be understood as an initial proposal, which needs to be further developed together with the interviewees, for instance through a ‘5 whys technique’ (Ohno, 1988), in order to better understand the root-cause of their problems. Further elaboration and testing of the proposed corrective actions in several cases remains beyond the scope of this article.
6.1. Increase the quantity and quality of LCI data

The diversity of practices within value chains of certain raw materials, resulting in a variety of sustainability profiles, is difficult to be captured by LCI/LC(S)A today. For example, large differences in water use and auxiliaries can exist between mining and metal production in different regions, depending on the material (geological character of the ore), the processing technology, the geographic location and technological and environmental priorities. Differences in the estimated global warming impact of different gold mining regions have revealed how improved equipment purchasing practices could contribute to significant energy savings (Stewart and Petrie, 2006). Whilst LCT within the industry has been central to identifying such opportunities, these variations are typically not fully captured by LCI databases commercially or publically available today, as they are typically either globally or regionally aggregated or insufficiently representative.

Conversely, if the goal of an LCA study is to quantify potential environmental impacts arising from a product system globally, a representative global average dataset is required, such as those that have often been made available by international metal commodity associations (Santero and Hendry, 2016).

On the one hand, a global average dataset is required, to quantify environmental impacts globally. On the other hand, specific LCI data could be relevant in order to capture the diversity of practices. While these requirements may seem to be in tension (global vs. specific), in fact they are complementary. In order to build a representative global average dataset, one needs specific LCI data from a representative sub-sample of operations. The ultimate solution for these issues is the generation and frequent update of LCI data from all mining and metallurgical operations, as well as the downstream fabricators and product manufacturers.

Additionally, there is a relevant market mechanism between mining and metallurgical operations (the generators of specific LCI data) and the downstream industries and society (the users of specific or global LCI data): the commodity market (Fig. 2 and Graphical Abstract). For sustainability assessment through a product-oriented perspective, this is a crucial issue, mainly because it renders most supply chains untraceable, while traceability is key for LCI. Moreover, other stages (than the commodity market) may affect the traceability of metals; for instance, it may already be reduced at smelter and refining stages, in the case of smelter/refinery that have inputs from more than one mine.

The raw materials sectors have undertaken many activities for sustainability assessment and have a practice of making data available to do so (as we pointed out in section 2). The key challenge is to make it available within a supply chain perspective, where in the end their products are constituents of final (consumer) goods.

Company reports and management frameworks, such as GRI and EMS, respectively, deal with data that are relevant for LCI and LCA. For instance, NOx emissions may be already accounted within a certain management framework (e.g., ISO 14,001), and/or reported in GRI reports, and/or used to generate other type of information. LCI, on the other hand, could make use of these data on NOx emissions as well. Similar approaches to use GRI/EMS reports for LCI/LCA have already been proposed in literature (Northey et al., 2013).

In both LCSA and LCA contexts, inventories on processes’ flows (LCIs) are essential. Currently, LCI data are available for a limited set of metals, such as copper, and in an aggregated way. Hence, an important gap is there for another series of metals and secondly, specificity in the environmental inventories (LCI datasets) can be improved in LCI Databases. The latter may be seen as a competitiveness concern for the sector in terms of confidentiality; however, it is worth exploring ways of providing more specific LCA data that do not reveal confidential items. Equally, if certain companies or operations at certain regions/countries are very well performing, it may become a commercial advantage. Green branding is definitely something to which western European consumers are open (c.f. the increase in EPD programs (Del Borgghi, 2013), as the PEF). Hence, green public procurement and product compliance may be converted to a gain instead of a constraint. The raw materials sectors are confronted with the societal request anyway, and a first concrete case is already there for aluminium beverage packaging, where an environmental sustainability certification scheme has been developed by the beverage industry (Laget, 2017). To support such schemes, a smart and cost-effective way to collect data, while taking care of possible confidentiality and data-abuse issues, will be important.

The corrective action (6.1) discussed here could support the sector regarding the use of unrepresentative LCI Datasets for metal-based products (section 5.1). Consequently, it could support to decrease the misuse of data in LCA studies and lack of communication (section 5.2) (Fig. 3). To be able to achieve that, one would need to develop and deliver to the mining/metal sector (e.g., associations) a value-proposition to provide data for product-oriented perspectives.
6.2. Incentivize the collaborative work between different scientific communities

LC(S)A is a multidisciplinary field, and collaboration with different sectors is key. It seems that with several other sectors, these collaborations were relevant to enhance the quality of LC(S)A studies and LCI data. For instance, LCA’s origins are in more industrialized products, but in the last years there was an outburst of (published) agricultural and food-related LCA studies (PRE, 2018). Regardless the reasons for this increase, the effort allowed LCA studies to become more accurate and robust in this sector. Moreover, nowadays LCA community is even able to make use of a high quality LCI database fully dedicated to agricultural and food-related activities, the Agri-footprint database (Agrifootprint, 2018).

A set of workshops, to allow better understanding of (i) LCA procedures (e.g., allocation) and (ii) mining, smelting and refining operations, could support the proposed corrective action, i.e., to incentivize the collaborative work between different scientific communities. Moreover, the creation of guidelines and white papers, as performed in Santero and Hendry (2016), are very relevant as well. Finally, scientific research projects, such as the SUPRIM project (which gathers experts from LCA, Geology and Mining), are another way to support this corrective action. One possibility to financially support those activities (workshops, guidelines/white papers, research projects) would be to leverage public funding to lower barriers to LCA-Mining co-learning (e.g. EIT Raw Material funding). Moreover, the development of professional codes and standards of practice for use of data in LCA would be helpful for a proper communication, but also to support the corrective action described in Section 6.1 (i.e., including the acceptance from the sector to provide more specific data via a value-proposition).

The increase in collaborative work between mining/metal sector and the LCA community (by either workshops, guidelines/white papers, research projects, etc.) could support to tackle the potential misuse of data in LCA studies and lack of communication (Section 5.2). Moreover, it could consequently support to increase the quality of LCI datasets (discussed in Section 6.1) (Fig. 3).

6.3. Better objectification of the benefits downstream of the sector

Traditional LCA accounts for the environmental impacts (‘footprint’) of a certain functional unit. However, this approach has its limitations in capturing benefits. There have been some proposals to incorporate the benefits of the product in the impact assessment (‘handprint’), i.e. considering the functionality of the product (Pajula et al., 2017). For instance, in the pharmaceutical sector, Quality-Adjusted Life Years (QALYs) at the use phase (i.e., benefits for the patient) are directly compared to the Disability-Adjusted Life Years (DALYs) over the entire life cycle of the product (i.e., burdens induced by the supply chain) (Debaye et al., 2016). Similar approaches have been used in other sectors as well (Gilbertson et al., 2014; Millstein et al., 2017; Stylianou et al., 2016).

Exploring the construction of a framework analogous to LCA for assessment of life-cycle benefits could also be investigated for the metal supply chain, not necessarily with the same indicators. For instance, different top-down studies have shown the benefits of Copper (Copper Alliance, 2018), e.g., in the implementation of renewable technologies targeted to reduce climate change emissions. A bottom-up approach (i.e., an LC(S)A study) could be performed for different copper applications, and further on comparing the environmental footprint of copper to its benefits at the application level. For that, the handprint of final products would need to be added in the LC(S)A studies.

We think that adding the handprint of final products next to the LC(S)A results could be a way to tackle the concern raised by stakeholders from metal/mining sector (in section 5.3), i.e., that the benefits of materials are not quantified in LC(S)A (Fig. 3). Moreover, it could consequently support to increase the quality of LCI datasets (discussed in section 6.1), because currently there is insufficient benefit to the industry to justify providing more detailed quality LCI data.

7. Final remarks and outlook

Through sections 3 and 4, it is possible to notice that the current practices of sustainability actions in the mining/metal sector (i.e., site-oriented perspectives) and product-oriented perspectives may differ in system boundaries, (environmental) impact categories and the object of study (the functional unit, in LCA). The differences in system boundaries is explained by a focus on the mine throughout the time for the former, and a focus on product supply chain for the latter (Graphical Abstract). The common area between these two different scopes is the operation at the mine up to the concentrated mining product, which is usually the beginning of the supply chain of metal-based products (red dotted-line rectangle in the Graphical Abstract). Currently, the connection between site-oriented and product-oriented perspectives, represented in the Graphical abstract by that common area, is not well communicated, which hinders societal understanding of the clear and immediate link between them. A few issues related to that and proposals for ways forward are discussed in sections 5 and 6, respectively. In fact, other sectors have already included product-oriented perspectives into their “basket” of approaches/tools for sustainability management in a collaborative way (e.g., plastics sector in Europe and some of the main metal producers internationally). Moreover, some tools already used by the metal/mining sector are already associating product-oriented perspectives with sustainability management, for instance, the last version of ISO 14,001 (ISO 14,001:2015) (ISO, 2015). Thus, there is a link between these tools (e.g., ISO 14,001) and product-oriented perspectives related to data and reporting.

Usually, strategic guidelines (e.g., Global Mining Initiative) and legislation/conformity requirements (e.g., ESIA) impose certain management procedures and/or specific studies that generate different types of data (Fig. 4). These data are further processed to generate different information, which fits into different levels of reporting (e.g., GRI), to different stakeholder groups. LCA (and LCI) may take advantage of such schemes, i.e., the data already generated by management frameworks (e.g., ISO 14,001) or specific studies can also be used to create LCI values, as explained in section 6.1. Moreover, if of interest, the LCI results may already be communicated to specific stakeholders, and/or used to generate an LCA study, which can be communicated through the same channels as GRI (following necessary GRI requirements). Additionally, reformating data collected for these sustainability initiatives (LCI/LCA and GRI reporting), and their reporting requirements, could lead to further matching of data with information needs and, as a consequence, more complete appreciation of the value chain. In Fig. 4, LCI and LCA are in green to highlight how they could fit into this scheme.

On the other hand, one important stakeholder for the mining industry is the host community, and there are a few challenges to incorporating some of the impacts host communities care about the most into the LCA framework (Awwuah-Offei and Adekpvedjou, 2011). Indeed, GRI and similar sustainability reporting schemes seek to assess mining/metal companies’ performance relative to a number of societal concerns that may not be addressed by classical product-based environmental LCA. This can be due to (i) difference in scope (mining activities vs. final products) and scale/granularity (site specific vs. generic modelling) of the environmental impacts (e.g., biodiversity, ecosystem services, soil and water pollution); (ii) issues of immediate on-site relevance for humans that rather represent impacts on social license to operate (e.g., labour conditions, corruption) or subjects of Risk Assessment (e.g., health and safety); or (iii) both (e.g., waste management and accidents; noise and vibration). Therefore, LC(S)A must be open for methodological improvements to capture some of these issues in order to provide additional value for the mining/metal sector, e.g., accounting for ecosystem services, spatial differentiation, and labour
conditions. Data assurance and adherence to codes or standards of LCA practice are probably also required.

Moreover, a product-oriented perspective could potentially be used in the mining/metal sector to go beyond site-based problem-solving and provision of LCI data to downstream industries (as mentioned in Section 4.2). LCSA may potentially be helpful to support overall societal acceptance of the sector. This might, for example, be achieved by supporting a Sustainable Development License to Operate (SDLO), as described by Pedro et al. (2017); increasing market access for commodities; or simply facilitating a better understanding of the connection between the benefits of final products and their supply chains. Nevertheless, it is important to acknowledge that solely environmental issues (i.e., LCA) may not be enough to achieve this acceptance due to the relevance of economic and social aspects/impacts (e.g., labor conditions, distribution of revenues) for the sector and its stakeholders. Hence, the development of social-LCA and life cycle costing (LCC) in a more operational way, together with consistent combination with (environmental) LCA (i.e., developing further the LCSA tool), is of relevance and an additional way in which a product-oriented perspective might support overall societal acceptance of the metal/mining sector.

Acknowledgements

We would like to thank for the financial support of KIC EIT Raw Materials for funding the project SUPRIM (project number 16121). Moreover, we would like to thank Prof. Dr. Johan Verrue (Verrue Consulting) and several external stakeholders (that we want to keep them anonymous) for their support on understanding and identifying different perceptions among different communities (LCA community, Mining Sector and Geologists).

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.resconrec.2019.02.018.

References
