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Applying social life cycle assessment in the early stages of a project development – an example from the mining sector

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Abstract

Purpose. Mining of raw materials have both positive (e.g. creation of values and jobs along their supply chains and the supply chains they enter) and negative social impacts (e.g. affecting safe and healthy living conditions of the local community or through the risk of corruption). A new mining paradigm, small-scale “switch-on switch-off” (SOSO) mining, is based on the design of a flexible and modular mining plant (MMP), aims at exploiting quickly and safely European small high grade deposits of raw materials, including critical. The goal of this study is to assess the social implications of this new mining paradigm on the value chain of the MMP.

Methods. A social hotspots assessment is conducted on pilot-scale operations of an MMP led in Bosnia and Herzegovina for the production of lead concentrate. The assessment is conducted using the performance reference point method. The background system is modeled through the PSILCA v2.0 database, while the foreground system is modeled using on-site data completed with PSILCA information.

Results. The assessment reveals six main hotspots induced by both the foreground and the background systems and occurring mainly in Bosnia and Herzegovina. These hotspots can be divided into three groups: 1) local preoccupations within the community: “contribution to environmental load” and “public sector corruption”, 2) measures that can be put in place by the MMP operator: “social responsibility along the supply chain” and “certified environmental management”, and 3) the conditions prevailing in the country: “sanitation coverage” and “workers affected by natural disasters”. Two sensitivity assessments are conducted in order to test the operating conditions of the MMP: switching from a diesel generator to a renewable source of energy supply and switching the country of operation to Greece, host of a similar deposit that could be potentially exploited thanks to the MMP. Switching the electricity supply system increases the overall risk due to the increase in potential impacts occurring on the renewable energy supply chain (e.g. battery manufacturing). When switching the country of operation to Greece, the overall potential impacts are predicted to decrease.

Conclusions. This study performed on pilot-scale operations provides information on potential social and socio-economic impacts and recommendations to limit these impacts in case of widespread use of the SOSO approach. In a broader perspective, having better knowledge of social implications linked to the mining and metals sector will help better understanding their implications in the various value chains they enter.

Keywords

Social life cycle assessment, small-scale mining, social hotspots, PSILCA, lead, metals, raw materials

1. Introduction

In 2018, raw mineral production in the European Union (EU) represented less than 5% of the global production (Farooki, Hinde and Lof, 2018). Meanwhile, metal consumption in the EU across various economic sectors represented 25%-30% of the global production (Hinde and Farooki, 2018). To reduce the risks implied by these disparities between production and consumption, the European Commission launched the “Raw Materials Initiative” in 2008, a strategy relying on three pillars: 1) fair and sustainable supply of raw materials from global market; 2) sustainable supply of raw materials within the EU and 3) resource efficiency and supply of secondary raw materials through recycling (European Commission, 2008). In late 2019, the President of the European Commission Ursula von der Leyen recalled the “*strategic security questions for Europe’s ambition to deliver the Green Deal*” that the access to resources has, including raw minerals among them (European Commission, 2019).

In a context where the metal market regularly fluctuates and Europe now lacks world-class deposits, the European funded project IMPaCT (<http://www.impactmine.eu/>; <https://cordis.europa.eu/project/id/730411>) proposes a new small-scale “switch on – switch off” (SOSO) mining paradigm where smaller, more flexible operations are designed to quickly and safely exploit European small, complex mineral deposits (Moore 2018; Moore et al. 2020; Sidorenko et al. 2020a). Use of a flexible mining modular plant (MMP) lowers capital expenditures for exploitation and eases access to the market for new mining actors. Furthermore, the SOSO approach permits a quick stop of the exploitation when metal prices fluctuate leading to an exploitation that is no longer economically viable. This characteristic gives the SOSO approach a short-term temporal nature that differs from the traditional mining sector. The SOSO approach primarily focuses on critical raw materials (CRM) as they are extracted in significantly smaller quantities than base metals, and there are numerous potential deposits not presently exploited in Europe, as referenced in the Minerals4EU database for example¹ (Moore 2018; Sidorenko et al. 2020a). In the future, the small-scale SOSO mining paradigm may also focus on secondary resource extraction from old tailings and legacy wastes from abandoned sites (Bodin and Bertrand, 2020). Sustainability considerations, including environmental and social implications, have been identified as key at an early stage of development of this new paradigm initiative (Moore et al. 2018; Sidorenko et al. 2020a, b).

Mining activities affect society both positively and negatively, as raw materials enter various value chains (from the low carbon energy sector to the agriculture sector) and accordingly participate to the jobs and the value creation along these chains. From a social perspective, mining shapes

¹ <http://minerals4eu.brgm-rec.fr/minerals4EU/> One data layer of the database specifically identify small scale complex deposits

1 local communities in many ways: from concrete changes in the physical and visual environment
2 to alterations in demographics and cultural characteristics (Sairinen et al. 2021). However, raw
3 materials exploitation also affects the environment, human health and rights in more adverse
4 ways (Mancini and Sala, 2018; Mancini *et al.*, 2019). Greater attention was centered on adverse
5 social impacts of the mining industry in the late 1990's at the same time as the growing concern
6 for sustainable development (Prno and Scott Slocombe, 2012). From this time, initiatives arose to
7 answer these concerns, such as the Mining, Minerals and Sustainable Development project, which
8 in turn led to various consultations in the early 2000's to assess the role of the mining and metal
9 sectors in the transition towards a sustainable development (MMSDP, IIED and WBCSD, 2002). In
10 addition, there was a growing interest for companies to engage in corporate social responsibility
11 (CSR) and public disclosure of information (Vintro and Comajuncosa, 2010), as for example
12 through the global reporting initiative that provides CSR documentation for the mining and metals
13 sector specifically (Global reporting initiative, 2010). In various countries, environmental and
14 social impact assessments are legal requirements to obtain an exploitation permit (IFG, 2019).
15 Moreover, since 2018 and as stated in its non-financial reporting directive, the EU has promoted
16 CSR for large companies and especially the identification, prevention and mitigation of existing
17 and potential adverse impacts their activities have on their supply and contracting chains.
18 Therefore, impacts related to at least environmental and social matters must be considered
19 (European Commission, 2014).

20 Various indicators and frameworks are proposed to assess the social sustainability of a mining
21 project: see for example Mancini and Sala (2018), Sairinen, Sidorenko and Tiainen (2021) and
22 Fonseca, McAllister and Fitzpatrick, (2013) for a review of different sets of frameworks. Some of
23 these frameworks specifically address the social implications at the mine site, such as social
24 impact assessment; however, assessing only the direct social implications of a mine site on the
25 local community fails capturing social impacts on the mine site value chain as mining might have
26 impacts on a national economy level (Lacey and Moffat, 2012). To assess both the direct and
27 indirect social implications of the mining sector, and more specifically of the SOSO mining concept,
28 sustainable tools such as life cycle thinking and more specifically social life cycle assessment (S-
29 LCA) can be used (Lacey and Moffat, 2012; Dewulf *et al.*, 2015; Balanay and Halog, 2016; Mancini
30 *et al.*, 2018). S-LCA was established in the early 1990's to consider the impacts that an economic
31 activity has on human well-being (Macombe *et al.*, 2011; Chhipi-Shrestha, Hewage and Sadiq,
32 2015; Russo Garrido *et al.*, 2018). In 2009, the UNEP-SETAC Life cycle initiative enabled a more
33 widespread application of S-LCA following the publication of guidelines that provide a framework
34 to perform S-LCA. A second edition of these guidelines was released in 2020 underlying the
35 evolution of S-LCA in a decade of practice (UNEP 2020). As with environmental life cycle
36 assessment (E-LCA), S-LCA aims to assess the potential positive and negative social and socio-

1 economic impacts that a product or service may have within its life cycle on various stakeholders,
2 including workforces, local communities, consumers, supply chain actors and the collective global
3 society (Andrews *et al.*, 2009). Many authors describe S-LCA and its methodology, and the reader
4 can refer to Benoît *et al.* (2010), Chhipi-Shrestha, Hewage and Sadiq (2015), do Carmo, Margni
5 and Baptiste (2017), Russo Garrido *et al* (2018) and Werker *et al.* (2019) for further description.

6 The goal of this paper is to assess the social and socio-economic hotspots of the SOSO mining
7 concept using S-LCA. As part of the SOSO modular plant testing phase, the MMP was deployed at
8 a mining site in Bosnia and Herzegovina (BiH - applying for EU membership since 1996) near the
9 town of Olovo to produce lead concentrate from cerussite ore. This project is a relevant new
10 development in the S-LCA field. First, by applying S-LCA on a production process still in the pilot
11 phase of its development. In fact, performing a hotspot assessment at this point of the project
12 development would underlines potential social risks and opportunities. Thus anticipating such
13 potential social issues gives the chance to identify mitigation measures early in the further
14 development steps of the project (Andrews *et al.*, 2009; Bergerson *et al.*, 2020; Rafiaani *et al.*, 2020).
15 Secondly, only a few S-LCA have been performed so far on the mining and raw material sectors in
16 general, they looked at: 1) the macro-assessment of potential social hotspots of the EU raw
17 materials supply chains, including the mining and metal producing sectors (Mancini *et al.*, 2018);
18 2) the potential social benefits of a phosphorous recycling policy (against phosphorus primary
19 production) in Japan (Teah and Onuki, 2017); 3) S-LCA case studies on construction materials
20 such as for example iron for steel and cement for concrete (Hosseinijou *et al.* 2014; Kutschke
21 2020); 4) the impacts on land use, employment and workers health & safety of the Australian coal
22 industry in the steel production chains (Weldegiorgis and Franks, 2014); 5) the social hotspots of
23 rare earth ore production routes (Werker *et al.*, 2019); and 6) the social hotspots of the mining
24 sector in Finland and Portugal (Di Noi and Ciroth, 2018).

25 In this context, this paper explores the social and socio-economic hotspots of lead concentrate
26 production through the MMP developed in the frame of the SOSO mining paradigm. This hotspot
27 assessment will provide knowledge regarding the most vulnerable spots on this specific lead
28 production value chain in order to establish mitigation measures in the frame of massive
29 deployment of SOSO mining in Europe, and more precisely in the Balkan region. The second
30 section of this paper details the method applied, the goal and scope definition, and the inventory
31 & impact assessment approach. The third section presents the obtained results and discusses
32 them through sensitivity assessments. Finally, the last sections put the results in perspective in
33 the frame of SOSO mining development and provide some recommendations for the future of
34 SOSO mining and its application in the EU.

2. Methods

2.1. Goal and scope

2.1.1. Context description

The assessment aims at exploring the potential social hotspots of mineral ore concentrate production through IMPaCT's MMP. The SOSO system consists in different several containerized modules (see following section for the complete description of the product system) to be quickly deployed in various locations to exploit high-grade ores. Through the frame of the IMPaCT project, the pilot MMP was deployed in Olovo (BiH) on an active cerussite (lead carbonate) ore mine. The S-LCA is performed on this case study. More particularly, this study is addressed to the MMP developers and operators to give them an overview of the potential social impacts that might arise on the whole system life cycle. The overall conclusions are more generally addressed to stakeholders of the raw materials sector.

Within the European continent, BiH is rich in mining heritage with several legacy sites as well as a number of operations and production plants that are active at present (Srebrenica for lead and zinc extraction, Jajce for ferro-alloys smelting, Mostar for alumina refining and aluminum smelting for example) (UNEP, 2009). In 2016, the mining and metal sector was employing more than 18,000 people for a production value of more than 470 million euros (Schmid, 2018, 2019). The town of Olovo also has a long history of lead mining within BiH, hence its namesake (Olovo means *lead* in Bosnian), with operations recently recommencing as the mining company *Minenco* obtained an exploitation license for the Olovo lead ore body in 2018. One of the particularities of BiH is its post-war context, because during the ethnic war in the 1990s, mining activities ceased with significant socio-economic implications. The consequences affected more particularly the population by reinforcing ethnic groups and the economic context that shifted from socialism to capitalism and became more open to private and foreign investments (Sidorenko, Orenius, *et al.*, 2020).

2.1.2. Scope description

The assessed product system is the same as in the E-LCA performed on the MMP deployment in Olovo for lead concentrate production and is described in Figure 1. It comprises the containerized MMP operations implemented on site through pilot tests in Olovo, BiH: the selective mining of the cerussite ore, the comminution module that allows reducing the particle size of the mined ore and the gravity separation module that produces a rich lead concentrate. The management of mineral processing waste is also considered through an on-site tailings management module. Finally, the overall installation is powered by electricity supplied from a diesel generator. Electricity supply

as well as water supply and ancillary services are considered as foreground processes as the mine operator has a direct influence on these processes. Upstream as well as downstream (waste management of equipment, at end of life) supplies considered as the background system are also specified in Figure 1. For a more technical description of the system under study, the reader can refer to the study performed by Beylot *et al.* (2020).

This product system allows the assessment of the following functional unit “the production of 1 tonne of lead concentrate with a lead content of 58.7%” using the IMPaCT-developed MMP on Olovo cerussite ore. This functional unit is equivalent to the one assessed in the E-LCA of the IMPaCT system by Beylot *et al.* (2020).

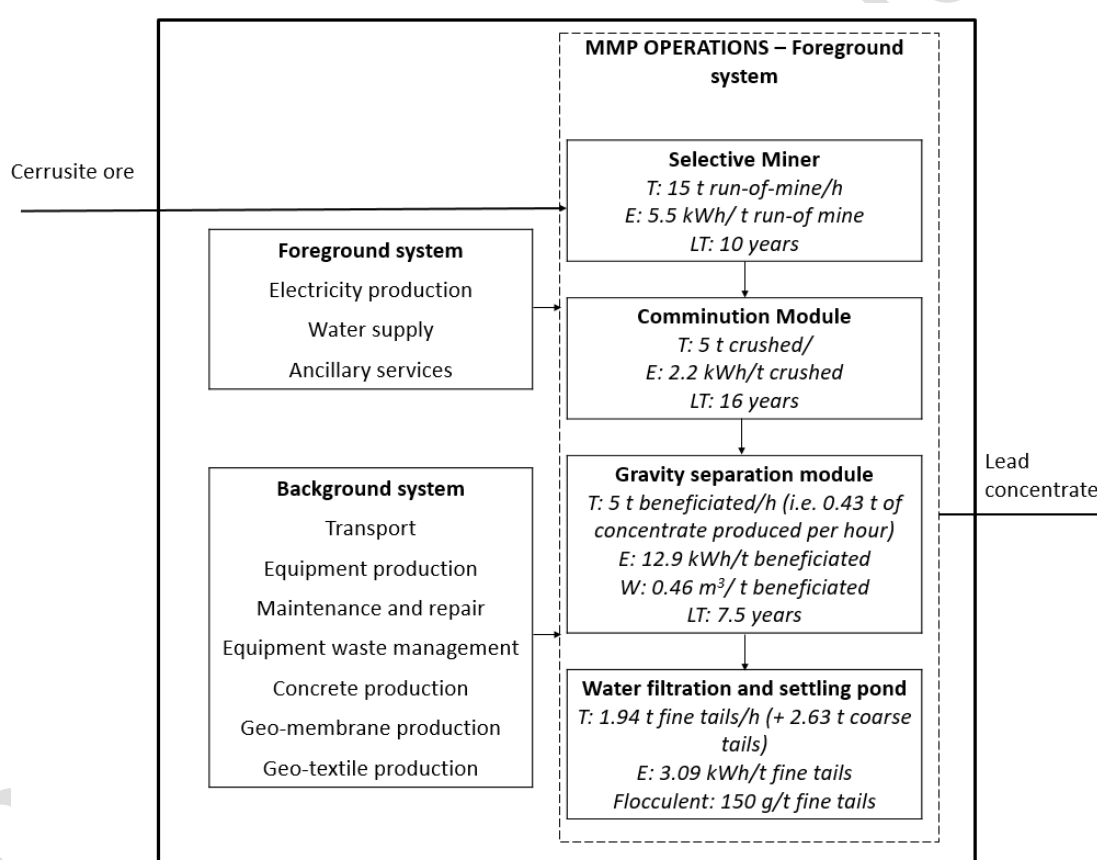


Figure 1 : Product system description and system boundaries of the lead concentrate production through the MMP, adapted from Beylot *et al.* (2020). The different acronyms state for:
T: throughput – E: Energy consumption – W: Water consumption – LT: Equipment lifetime

Social life cycle impact assessment methods are usually divided into two categories: type I methods (or performance reference point methods) where social and socio-economic impacts are measured compared to a reference performance for a similar activity; and type II methods where

the inventory is transformed into impacts through cause-effect relations (see the following for the definition of type I and type II: Chhipi-Shrestha, Hewage and Sadiq, 2015; do Carmo, Margni and Baptiste, 2017; Russo Garrido *et al.*, 2018, UNEP 2020). Here, the goal is to assess the potential social hotspots of the described product system. To perform this assessment, type I S-LCA is chosen. Figure 2 presents the overall methodology followed to model the product system. It distinguishes the methodologies used to model respectively the foreground system (unit processes are identified in Figure 1) and the background system.

2.1.3. Modelling of the background system

The procedure to model the background system is indicated in the far right column in Figure 2. The background system is here modeled by using the PSILCA v2.0 database (Eisfeldt and Ciroth, 2017). It is built on the EORA multi regional input-output database to model the value chains mobilized by a specific activity in a specific country, using monetary units to quantify the exchanges (see Lenzen *et al.* for a description of the EORA database (2013)). PSILCA provides social and socio-economic indicators for five stakeholder categories that are potentially affected: workers, value chain actors, society, local community and consumers. For each stakeholder category, a set of indicators (65 in total) are qualified using international statistics and then transformed using a risk/opportunity scale and a weighting system. The latter is based on an activity variable, defined in PSILCA as the hours worked to produce one dollar of the activity. The social impact (expressed in medium risk hours) is then determined using the equation described in Figure 2.

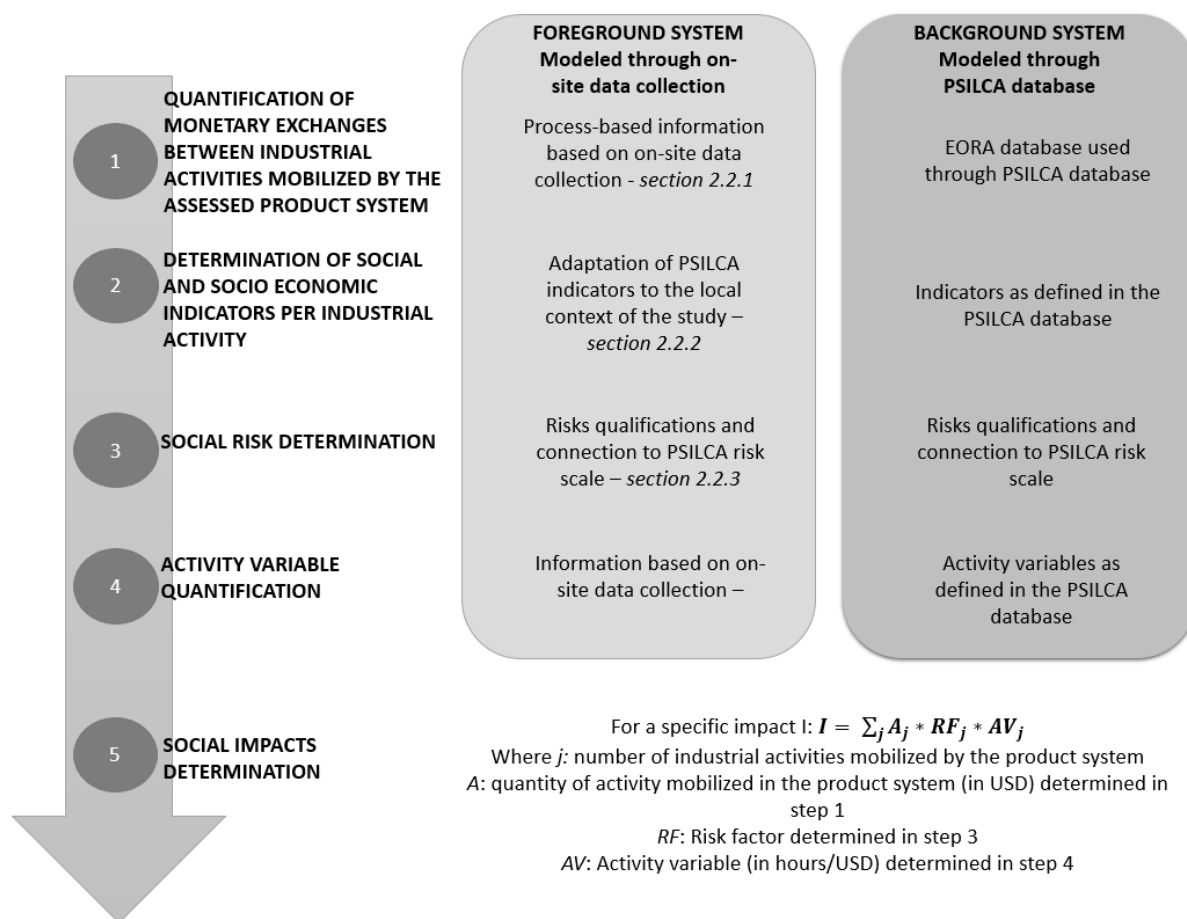


Figure 2: Procedure to determine the potential social impacts of a product system using specific on-site information and the PSILCA v2.0 database. Applied in this study to the case of a lead concentrate production in Olovo, BiH

2.1.4. Modelling of the foreground system

Contrarily to the background system, the foreground system is modelled based on information principally collected on-site. Therefore, as shown in the central column on Figure 2, the first step is to quantify the exchanges between the foreground system and background economic activities, in monetary units. This quantification is performed considering four intermediary steps: 1) the compilation of the inventory of intermediate exchanges in mass and energy units; 2) the identification of the location of these economic exchanges (e.g. production of infrastructures in the UK); 3) the conversion from physical to monetary units; and 4) the mapping of these flows to the flows of activities available in PSILCA's nomenclature. Section 2.2.1 describes in details this quantification.

Then, for each unit operation present in the foreground system, the most relevant socio and socio-economic indicators for this study need to be chosen. In the PSILCA v2 database, 65 indicators are considered which are classified into 19 categories representing specific social themes and five

1 stakeholder groups (see the supporting information document). In the following, only the
2 categories considered to be key in the context of this study were selected and used in the
3 assessment. Each category identified as relevant considering at least one of three following
4 approaches/studies has been considered for this study: 1) consideration of the study of Mancini,
5 et al. linked to the raw material sector in Europe (2018), 2) hotspot assessment of the 'Mining and
6 quarrying sector' using PSILCA database, 3) consideration of the results of field interviews
7 conducted in the local community in 2017. Section 2.2.2 describes the finally chosen indicators as
8 well as their risk level definition.

9 Once the risk level has been defined for the social and socio-economic indicators associated to
10 each of the foreground unit operations, the risk level is translated into a semi-quantitative score
11 (risk factor in Figure 2). The method available in the PSILCA database is used in the following
12 (Very low risk is associated to the factor 0.01; Low risk: 0.1; Medium risk: 1; High risk: 10; Very
13 high risk: 100) (Eisfeldt and Ciroth, 2017).

14 Finally, the activity variable (AV) is the remaining parameter that needs to be quantified and
15 implemented in the equation of impact calculation (Figure 2). In PSILCA, AV is set as the time
16 worked expressed in hours to produce one USD in each unit operation. In this study, AVs for the
17 foreground system are defined based on on-site information when available or on assumptions
18 and expressed in hours per unit of output. Table 3 provides the values of activity variables
19 corresponding to each foreground unit operation for which manpower is required.

20 The overall potential hotspots calculations is performed using the PSILCA v2.0 database
21 manipulated through the OpenLCA 1.10 software (<https://openlca.org/>) and using a cut-off value
22 of 1e-6 (i.e exchanges representing less than 1e-6 USD are not represented) to model the entire
23 product system.

24

1

Table 1: Activity variables defined for the foreground unit operations

Unit operations	Activity variable in hours per unit of outputs	Data sources and calculations
Selective mining	6.7e-5 hours/kg	Based on data in Figure 1 (15 t run of mine/hours)
Comminution	2e-4 hours/kg	Based on data in Figure 1 (5 t crushed/hours)
Gravity separations	5.03e-3 hours/kg	Based on data in Figure 1 (0.43 t concentrate/hours)
Fine tailings management	4.33e-4 hours/kg	Based on data in Figure 1 (1.94 t fine tails/hours)
Electricity supply	8.68e-4 hours/kWh	On-site data: 0.31 USD/kWh Assumption: the PSILCA activity variable for the unit operations "Electricity by oil, UK" is: 0.0028 hours/USD So here: $0.31 \times 0.0028 = 8.68e-4$ hours/kWh
Water supply	4.79e-3 hours/m ³	On site data: 0.32 USD/m ³ Assumption: the PSILCA activity variable for the unit operations "Electricity, gas and water supply, BA" is: 0.01497 hours/USD So here: $0.32 \times 0.01497 = 4.79e-3$ hours/m ³

2

3

4 2.2. Social life cycle inventory and impact assessment

5 2.2.1. Quantification of exchanges between industrial activities

6 The quantification of monetary exchanges between industrial activities is firstly based on the life
7 cycle inventory, in mass and energy units, compiled and used by Beylot et al. to perform the
8 environmental LCA (2020; see the supporting information document for a recall of this inventory).
9 Accordingly, in the following model the same assumptions as those made by Beylot et al. are
10 considered; some of them are recalled in Figure 1, others can be found in the supporting
11 information document.

12 Moreover, the location of the economic activities is set to be representative of the pilot tests
13 performed as part of the IMPaCT project. The selective miner and the gravity separation modules
14 are designed and produced in the United Kingdom as well as the containers used to move these
15 modules; and the comminution module is designed and produced in France, as well as the
16 container used to move this module. All the MMP operations take place in BiH, in the town of
17 Olovo. It is also the case for the water supply and the electricity production activities, the MMP

1 maintenance and repair operations and the construction of the concrete pillars needed to stabilize
2 the comminution and the gravity separation modules during operations. Transport of the MMP is
3 also assumed to occur in BiH as it is prospected to deploy the MMP on mine sites in the Balkans
4 region. As the whole MMP is mainly developed and operated by institutions from the United
5 Kingdom, it is assumed that the end of life of both the containers and the MMP modules will occur
6 in the United Kingdom. Finally, the geo-membrane and the geo-textile used in the tailings
7 management unit operation are respectively produced in Austria and Italy (Roethe 2020).

8 Moreover, the conversion from physical units to monetary units, in United States Dollars (USD, as
9 the currency used in the PSILCA database), is based on various sources of information: 1)
10 interviews with members of the project in charge of the MMP development, deployment and
11 operations; 2) technical handbook providing capital and operation expenditures for mining
12 equipment (CostMine, 2019); and 3) grey literature (see the supporting information document
13 for details on values considered and associated datasources). The quantification of the exchanges
14 in the foreground activities (as described in Figure 1) is available in details in the supporting
15 information document. A limit of this quantification is that it is based on material flows only,
16 monetary exchanges of specific service activities are therefore not considered in the foreground
17 activities. They are however considered in the background activities as part of the PSILCA
18 modelling.

19 Finally, for each operation modelled using the PSILCA database, the most relevant industrial
20 activity was chosen based on the activity description in international and national industrial
21 sectors classification systems (such as the NAICS system - <https://www.naics.com/> or the ISIC
22 system - <https://ilostat.ilo.org/resources/methods/classification-economic-activities/>). The
23 supporting information document provides the PSILCA activities chosen to model the system unit
24 operations and the quantified exchanges between each of the unit operations (including data
25 sources).

26 2.2.2. Selection of social and socio-economic indicators for the foreground 27 industrial activities

28 The selection of the social and socio-economic indicators for the foreground industrial activities
29 is based on the assessment of three different sources of information: 1) A study considering the
30 subcategories relevant for the S-LCA of the raw materials sector, 2) a hotspots assessment
31 conducted on the 'Mining and quarrying sector' in BiH as modeled in the PSILCA v2.0 database
32 and 3) meetings with local representatives.

33 Firstly, a study performed by Mancini *et al.* selected the subcategories relevant for the S-LCA of
34 the raw materials sector based on three conditions: 1) their relevance to raw materials and the

1 policy sectors; 2) their potential impacts calculated with the PSILCA database; 3) the reliability of
2 the data and appropriate geographic & technical resolution for the indicator data (2018). Based
3 on these conditions, seven subcategories emerged. They are displayed in Table 2 and are linked
4 to the four stakeholders groups: society, value chain actors, local community and workers.

5 The hotspot assessment conducted on the 'Mining and quarrying' sector in Bosnia and
6 Herzegovina as modeled in the PSILCA database underlines mainly social impacts on the value
7 chain actors group. This is due to the quantification as 'very high risk' for three of the indicators
8 ('public sector corruption', 'social responsibility along the supply chain' and 'presence of anti-
9 competitive behavior or violation of anti-trust and monopoly legislation'). If the risk
10 quantification of the first indicator is based on national Bosnian data, for the last two, the data
11 quality is poor as there is either no specific reference value (and is rated in this case as "very high
12 risk" in the PSILCA database) or data is extrapolated from another country (United States here).
13 Besides these hotspots on the value chain actors group, the hotspot assessment also underlines
14 two other groups potentially affected: the local community (with the indicators subcategories
15 'access to raw material resources' and 'safe and healthy living conditions') and the workers (with
16 the 'health and safety' indicator).

17 Finally, during spring 2017 and winter 2018, several meetings were organized with the local
18 community representatives in Olovo to investigate social perspectives to mining operations. In
19 June-July 2018, sixteen in-depth thematic interviews with selected representatives of Olovo
20 community were conducted and completed with formal meetings with mining company
21 representatives, municipality and government officials. These discussions helped to better
22 understand the socio-economic context of the areas. The interviewees were identified through a
23 stakeholder analysis. The interviews focus on finding the stakeholders attitudes towards the
24 reopening of mines and their potential social benefits. The detailed findings of these thematic
25 interviews can be found in Sydd, Orenius, *et al* (2020) and Sydd, Sairinen, *et al.* (2021). Local
26 inhabitants see the mining industry as an opportunity, especially for direct and indirect **job**
27 **creation** and **remigration** of past habitants that previously left the town for larger cities in and
28 outside of BiH. However, the local community representatives fear that the municipality and in
29 turn the local community will not economically benefit enough from the mining activity, and that
30 the distribution of the social benefits will not be fair enough. To that extent, the local community
31 representatives fear a risk of some forms of **corruption**. This fear might mainly be due to the level
32 of complexity of BiH's governance and the lack of clarity about responsibilities across different
33 levels of governance (Sydd, Orenius, *et al*, 2020). In BiH, the State is the first level of governance,
34 which is then divided into three entities (Federation of Bosnia and Herzegovina, Republika Srpska
35 and Brcko district). The third level of governance is the cantonal level, which divides down further

into municipalities. If the local community qualifies its relationship with the municipality as “easy”, it feels it “constraining” with the higher levels such as the State or the Federation of Bosnia and Herzegovina. Moreover, this level of complexity makes it harder to follow local legislation and environmental regulations around a specific site or project. The local community is most concerned **by the protection of the environment**, particularly maintaining a sustainable supply of clean water as Olovo is known for its recreational activities around water (such as fishing and spas) (Sydd, Orenius, *et al*, 2020). In general, **health and safety conditions** for the local community and workers are of concerns for the community. Corruption and health and safety living conditions are indicators that are also potential hotspots when assessing the ‘Mining and quarrying’ sector in BiH as modeled in the PSILCA database (see above).

Table 2 provides the list of the 14 subcategories which emerged from this assessment (the associated indicators are displayed in the supporting information document) and that are kept here to assess the foreground unit operations. In the assessment, only these subcategories are considered. It is noteworthy that this list distinguishes four stakeholder groups only, as the ‘consumers’ group has not been identified a key group in this evaluation. One category of indicators (“Health and safety”) has been identified as relevant based on the three approaches, while six other categories have been identified based on two approaches. The eight remaining are selected through one investigated source of information only. Among these subcategories ‘Respect of indigenous rights’ is identified as relevant in the study of Mancini et al. (2018) only. However, no specific indigenous population is identified in BiH leading to the qualification as ‘No risk’ in the PSILCA database, while other mining companies are operating for example in countries including various indigenous population (South Africa, China, Canada or Brazil for example). Lastly, it should be noted that all PSILCA subcategories for Local community are kept in the study.

Table 2: Subcategories of social and socio-economic indicators kept in the assessment of the foreground unit operations.

The initials in parenthesis indicate by which mean the category was defined as relevant (HA: hotspot assessment, M: study of Mancini et al., 2018, FI: field interviews)

Society	Value chain actors	Local community	Workers
Contribution to economic development (FI, M)	Corruption (HA, M, FI) Fair competition (HA) Promoting social responsibility (HA)	Access to raw material resources (HA, FI) Safe and healthy living conditions (HA, FI) Local employment and migration (FI, M)	Health and safety (HA, FI,M) Fair salary (FI, M) Social benefits (FI) Working time (FI) Child labor (M)

		Respect of indigenous rights (M)	Freedom of association (M)
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2.2.3. Definition of the risk levels associated to each indicator for the foreground industrial activities

For each of the foreground unit operations modeled in the system (see section 2.2.1), the 52 indicators, the same as the ones used in the PSILCA database to assess these 14 subcategories, are qualified to consider the specific context of the MMP operations in Olovo. This qualification is firstly based on on-site data collection (e.g. regarding the category 'Health and safety' for the workers stakeholder group, for which specific on-site assessment were conducted during the deployment of the MMP operations). To fulfill data gaps, different techniques and data sources are used. First, specific assumptions are derived when there is no sufficient evidence to precisely quantify some indicators, in the context of a pilot operation, such as 'rate of accidents at workplace'. Assuming the rating of these indicators here as very low risk means that less than 750 non-fatal accidents per 100,000 employees occur and less than 7.5 fatal accidents (Eisfeldt and Ciroth 2017). If during the MMP pilot operations in Bosnia, no non-fatal neither fatal accidents were reported, in the PSILCA database, these two indicators for the Mining and quarrying sector in Bosnia are qualified as 'No data'. For these indicators, the qualification 'No data' is equivalent to the qualification as 'low risk' in terms of risk factors. Given this assumption, these figures will have to be reassessed in the course of the potential future widespread use of MMP operations to check if these risks are not underestimated in this study considering a pilot scale only.

Secondly, if available, specific statistics for the Olovo region or for Bosnia and Herzegovina are used. Thirdly, the direct emissions available from the environmental LCA conducted by Beylot et al. are used for the indicators in the subcategory 'contribution to environmental load' for the local community stakeholder group on the 'safe and healthy living conditions' category. These direct emissions are associated with the electricity production from a diesel generator, to the particulates emissions due to the selective miner and the tailings management (Beylot et al. 2020). And, finally, if no specific data are available to either quantify the indicators or to qualify their risk level, data from the Bosnian 'Mining and quarrying' sector as modeled in the PSILCA database are considered. Table 3 provides the list of the 20 (out of the 52 selected) indicators that are modified to take into consideration the specific context of this study. These indicators are then transformed into risk qualification by applying the risk scale defined in the PSILCA database (see Eisfeldt and Ciroth for the risk scale description associated to each indicator (2017)). These 52 indicators are then, in the social life cycle impact assessment step, transformed into 39 single risks subcategories based on the classification used in the PSILCA database (see the supporting information

- 1 document) and that are expressed in medium risk hours representing the addition of all activities
- 2 risk factors scaled by their hours of operation (see Figure 2).

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Table 3: Indicators adapted to the context of the study for the foreground unit operations: value and associated risk qualification

Stakeholder group	Subcategory	Indicator	Value in the context of the study	Associated risk qualification	Data representativeness	Data source
Workers	Child labor	Children in employment, female	9%	Medium risk	Country specific	Specific statistics - Bureau of International Labor Affairs, 2018
Workers	Child labor	Children in employment, male	9%	Medium risk	Country specific	Specific statistics - Bureau of International Labor Affairs, 2018
Workers	Child labor	Children in employment, total	9%	Medium risk	Country specific	Specific statistics - Bureau of International Labor Affairs, 2018
Workers	Health and safety	Presence of sufficient safety measures	Qualified as very low risk	Very low risk	Specific to the mine site	Data collected on site - on-site risk assessment (Doyle 2020a, b)
Workers	Health and safety	Rate of fatal accidents at workplace	Qualified as very low risk	Very low risk	Specific to the mine site	Data collected on site - on-site risk assessment (Doyle 2020a, b)

Workers	Health and safety	Rate of non-fatal accidents at workplace	Qualified as very low risk	Very low risk	Specific to the mine site	Data collected on site - on-site risk assessment (Doyle 2020a, b)
Workers	Fair salary	Sector average wage, per month	<i>Confidential data</i>		Specific to the mine site	Data collected on site
Workers	Working time	Weekly hours per employee	<i>Confidential data</i>		Specific to the mine site	Data collected on site
Local community	Local employment	Unemployment rate in the country	18.4%	Very high risk	Country specific	Agency for Statistics of Bosnia and Herzegovina, 2018
Local community	Safe and healthy living conditions	Contribution of the sector to environmental load, CO emissions	No emissions except for the electricity production : 3.34e-3 kg/USD	No risk for the mining and concentration operations; but very high risk for the electricity production through a diesel generator	Specific to the mine site	Calculations derived from the inventory compiled by Beylot <i>et al.</i> (2020)
Local community	Safe and healthy living conditions	Contribution of the sector to environmental load, total GHG emissions expressed in kg CO ₂ eq	No emissions except for the electricity supply: 2.23 kgCO ₂ eq/USD	No risk for the mining and concentration operations; but very high risk for the electricity production through a diesel generator	Specific to the mine site	Calculations derived from the inventory compiled by Beylot <i>et al.</i> (2020)

Local community	Safe and healthy living conditions	Contribution of the sector to environmental load, NMVOC emissions	No emissions except for the electricity supply: 9.13e-4 kg/USD	No risk for the mining and concentration operations; but very high risk for the electricity production through a diesel generator	Specific to the mine site	Calculations derived from the inventory compiled by Beylot <i>et al.</i> (2020)
Local community	Safe and healthy living conditions	Contribution of the sector to environmental load, NOx emissions	No emissions except for the electricity supply: 1.57e-2 kg/USD	No risk for the mining and concentration operations; but very high risk for the electricity production through a diesel generator	Specific to the mine site	Calculations derived from the inventory compiled by Beylot <i>et al.</i> (2020)
Local community	Safe and healthy living conditions	Contribution of the sector to environmental load, PM10 emissions	No emissions except: - Electricity supply: 7.59e-4 kg/USD - Selective mining: 2.37e-3 kg/USD	Very high risk for the selective miner and the electricity production through the diesel generator, no risk for the other operations	Specific to the mine site	Calculations derived from the inventory compiled by Beylot <i>et al.</i> (2020)
Local community	Safe and healthy living conditions	Contribution of the sector to environmental load, SO2 emissions	No emissions except for the electricity supply: 1.88e-5 kg/USD	No risk for the mining and concentration operations; but very high risk for the electricity production through a diesel generator	Specific to the mine site	Calculations derived from the inventory compiled by Beylot <i>et al.</i> (2020)

Local community	Safe and healthy living conditions	Sanitation coverage	47 %	Very high risk	Specific to the town where the mine site is located	Specific statistics for the Olovo region Vicanovic and Vilic-Svraka, 2016
Society	Contribution to economic development	Illiteracy and youth illiteracy rates, female	6.55 %	Medium risk	Specific to the town where the mine site is located	Specific statistics for the Olovo region Agency for Statistics of Bosnia and Herzegovina, 2016
Society	Contribution to economic development	Illiteracy and youth illiteracy rates, male	0.69%	Very low risk	Specific to the town where the mine site is located	Specific statistics for the Olovo region Agency for Statistics of Bosnia and Herzegovina, 2016
Society	Contribution to economic development	Illiteracy and youth illiteracy rates, total	3.64%	Low risk	Specific to the town where the mine site is located	Specific statistics for the Olovo region Agency for Statistics of Bosnia and Herzegovina, 2016

3. Results and discussion

3.1. Social impact hotspots

3.1.1. General considerations

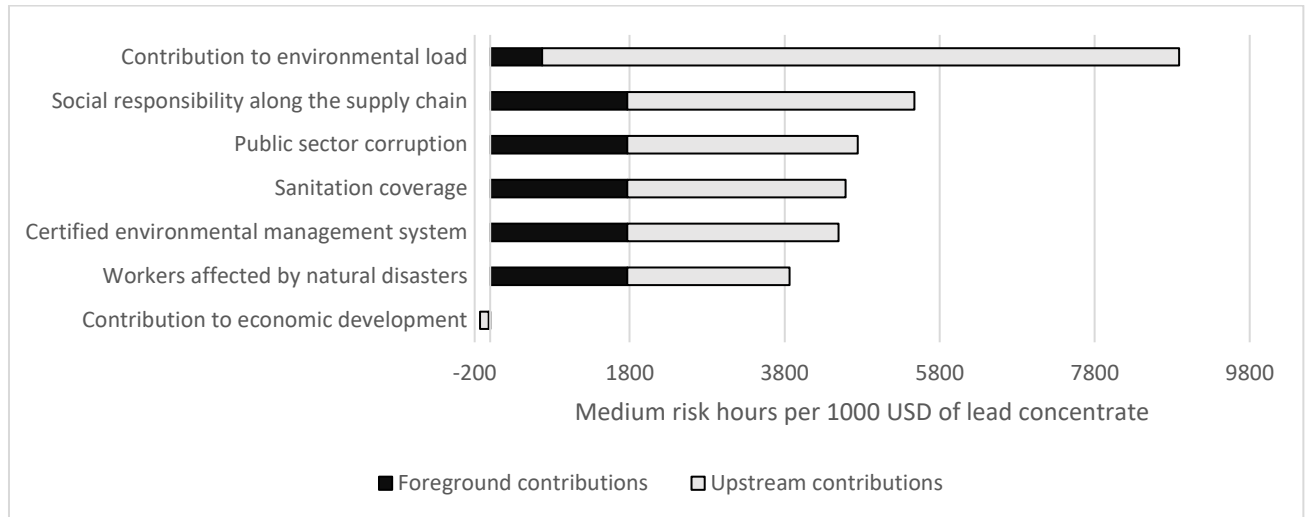


Figure 3 Main potential social impact hotspots and opportunities for the system under study and contribution of the foreground system against upstream impacts

Figure 3 presents the main potential social hotspots of the system under study. The six main hotspots represent almost 75% of the overall impacts resulting from 1tonne of lead concentrate production in Olovo as modeled in this study and expressed in medium risk hours. The remaining 25% is distributed among the other 39 subcategories that have been selected for this study (see section 2.2.3) whose contributions vary from 4.4% to 0.3% while the hotspots contributions vary from 20.7 % ('contribution to environmental load') to 9% ('workers affected by natural disasters'). Figure 3 also indicates the opportunity 'contribution to economic development', the only opportunity that is indicated on Figure 3 using a negative figure. This social opportunity 'contribution to economic development' is modeled in PSILCA considering the economic (through, in particular, the gross domestic product – GDP) and the educational (through illiteracy rate and the public expenditure spent on education) (Eisfeldt and Ciroth, 2017).

These six hotspots can be classified into three different categories:

- A first category 'Local preoccupations within the community' with the specific hotspots 'contribution to environmental load' and 'public sector corruption' that are directly linked to concerns expressed by the local community (see sections 2.2.2 and 3.1.2).
- A second category 'Measures that can be put in place by the MMP operators' that incorporates the hotspots 'Social responsibility along the supply chain' and 'certified environmental measures'. The subcategory 'public sector corruption' could also, in a certain extent be classified here. The way to qualify these hotspots, in PSILCA, is directly

linked to management structures that can be put in place by the operator of the assessed system or its partner companies (see section 4.2).

- Finally, a third category 'Conditions prevailing in the country' that regroups the hotspots 'Sanitation coverage' and 'Workers affected by natural disasters' are qualified in PSILCA using country generic data and focus rather on the national context in which the system is operating regarding the overall sanitation access for the population or if the population is subject to natural hazard risks (see more particularly section 4.2).

Among these six hotspots, only the indicators in the subcategory 'contribution to environmental load' were quantified and qualified for the foreground system based on specific on-site data in particular, the on-site air emissions resulting from the diesel generator (cf. *Table 2*). The medium risk hours are the same for the foreground system for the five sub-categories 'social responsibility along the supply chain', 'public sector corruption', 'sanitation coverage', 'certified environmental management system' and 'workers affected by natural disasters'; this is due to the fact that the associated indicators are rated the same for all foreground activities (as 'very high risk', see the supporting information document).

As stated above, these five specific subcategories were not adapted to consider the foreground system but they represent the rating performed in PSILCA for the 'Mining and quarrying sector in BiH. For the subcategories 'Workers affected by natural disasters', 'Sanitation coverage' and 'Public sector corruption' (indicator 'Public sector corruption'), the rating is based on country specific data. For the subcategory 'Public sector corruption' (indicator 'Active involvement of enterprises in corruption and bribery') and the subcategory 'Social responsibility along the supply chain' no data were available for the mining sector in BiH, there are so rated by default respectively "low risk" and "very high risk" in PSILCA. Finally, the subcategory 'Certified environmental measures' is measured in PSILCA using the number of ISO 14001 norms deployed in the country, in the specific sector and normalized by the number of employees in the sector. It is so a reflection of one environmental management system tool only. Given these limits, these hotspots do not represent actual impacts of the system under study but rather points of attention that the MMP operator should consider when deploying at large the MMP system.

Finally, it should also be noted that each stakeholder category is affected by at least one hotspot, apart from the 'society' stakeholder, which is only related to one opportunity 'contribution to economic development'.

3.1.2. Comparison with other assessments

The main identified hotspots are the same as the ones from the 'mining and quarrying' sector in BiH as modeled in the PSILCA database; only the hotspots contribution ranks differ as showed in Figure 4. However, for some of the 39 risks assessed, their contribution differs between the

generic assessment and this specific assessment. This is for example the case for the ‘unemployment’ hotspot for which the contribution differs by an order of magnitude: being greater in the case of the lead ore production assessment. In fact, foreground activities information was adapted to the case of the country and so rated as ‘very high risk’ resulting in an impact factor of 100 (see the supporting information document); while for the generic dataset, ‘no data’ are affected to this risk (with an impact factor of 0.1) leading to potential underestimation in the case of the generic ‘Mining and quarrying’ dataset.

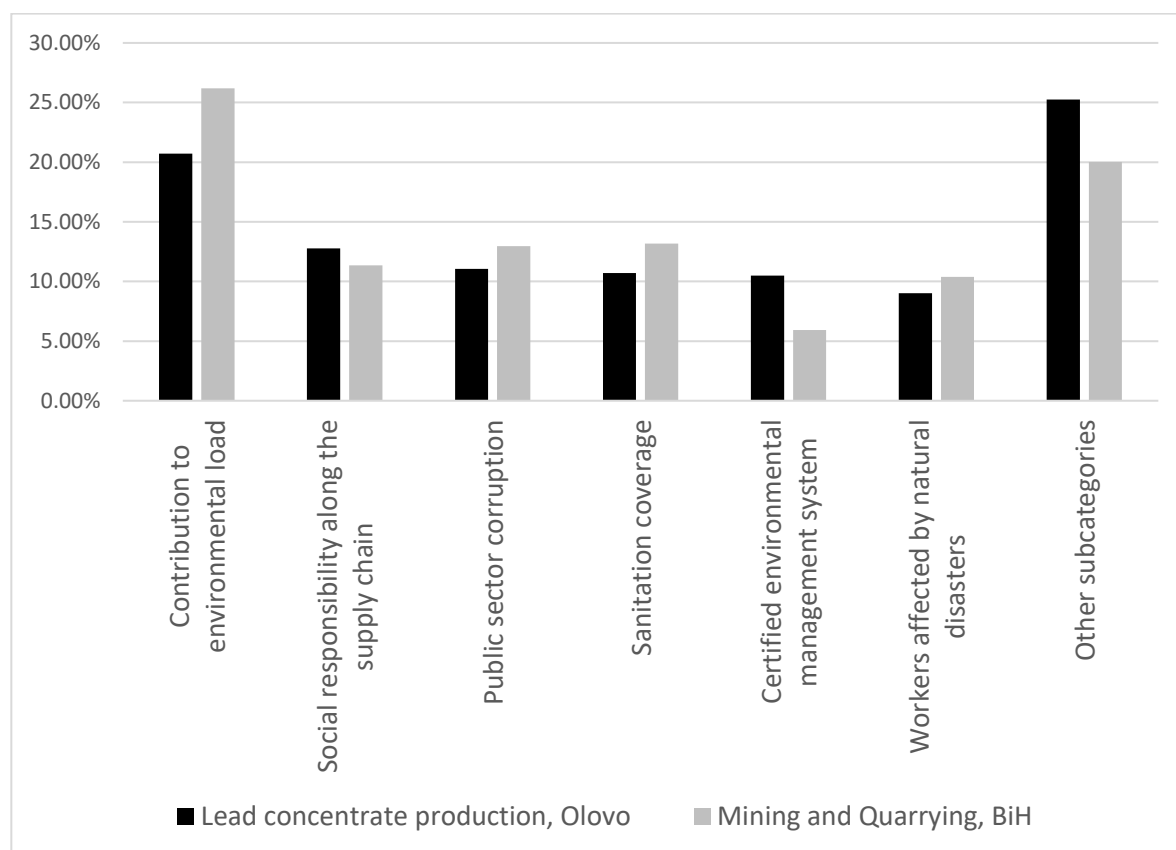


Figure 4 : Comparison of hotspots contributions between the two systems ‘Mining and quarrying, BiH’ as modeled in the PSILCA database and ‘Lead concentrate production, Olovo’ as modeled in this case study

The JRC study identifies risks such as ‘Migration’, ‘Respect of indigenous rights’ or ‘Children employment’ as potential risks for the raw material sector (see section 2.2.2 and the supporting information document) (Mancini *et al*, 2018). In this case study of lead production in BiH, these three risks contribute to 2% of the overall impacts with ‘Child labor’ risks adapted to consider specific country information (see Table 2). Furthermore, the hotspots ‘Migration’ and ‘Respect of Indigenous rights’ are risks here occurring mainly outside BiH.

Concerning the link between the hotspots and the local community preoccupations (see section 2.2.2), the preoccupation relating to the safe and healthy conditions for the community and the workers is linked to one hotspot here ('contribution to environmental load' linked to the 'safe and healthy living conditions' of the local community stakeholders category). It has to be noted that, however, this hotspot does not consider the specific effect of the activities on the local water resource that is of interest for the local population. The hotspot 'public sector corruption' can be put in parallel with the lack of trust the local community has with higher levels of governance. During the interviews, the local community also underlines the safe and healthy conditions for the workers. In this assessment, it should be recalled that safety measures were specifically put in place on the mine site to mitigate the occurrence of accidents and therefore the associated social indicators were adapted to consider these actions taken. Consequently, the subcategory 'Safety measures' is not identified as a hotspot. In this context, the foreground activities contribution dropped below 0.4% for three indicators ('presence of sufficient safety measures', 'rate of fatal accidents' and 'rate of non-fatal accidents') whereas, these contributions were between 1.6 and 14% in a Bosnian context.

3.1.3. Main hotspots location

Table 4 gives an overview of the greatest contributors to two distinct hotspots ('contribution to environmental load' and 'social responsibility along the supply chain') and the opportunity 'contribution to economic development'. Regarding 'contribution to environmental load', if activities in BiH contribute to 60% of the hotspots, only a small part is due to the emissions occurring on site, with a majority of those attributed to the BiH sector 'Petroleum, chemical and non-metallic mineral products' that is used to model the supply of diesel for the generators. For this sector, the 'Contribution to the environmental load' is rated as 'very high risk' in PSILCA explaining its contribution to the total potential impacts. However, due to the aggregation of different sectors in 'Petroleum, chemical and non-metallic mineral products' this contribution might be overestimated. The second contributing country is the United Kingdom where manufacturing of the selective miner and the separation equipment has the greatest impact.

The activities contributing to the hotspots are mainly occurring in BiH and the United Kingdom, which can be explained by the system's supply chains in which the majority of dollars are spent in both countries. For specific hotspots, the main contributing activities are occurring in BiH mainly (80% for 'public sector corruption', 83% for 'sanitation coverage' and 98% for 'workers affected by natural disasters') and are linked to the foreground system. The contribution of BiH is particularly important for the indicator 'workers affected by natural disasters' that represents risks due to natural hazards and that are independent from the employers (Eisfeldt and Ciroth, 2017). This indicator is generic for all sectors in BiH and is rated as 'very high risk' for the country

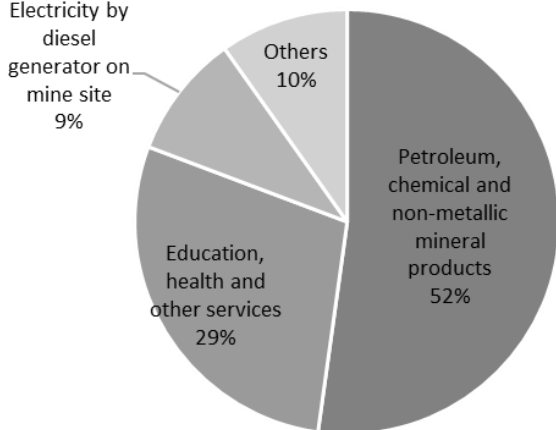
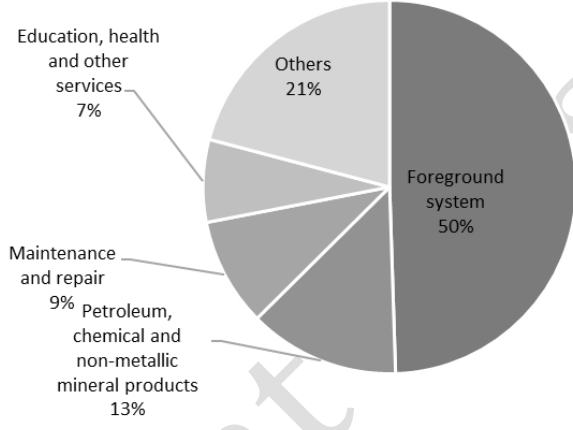
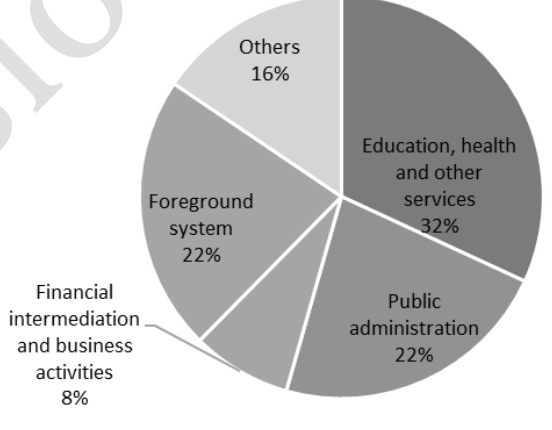
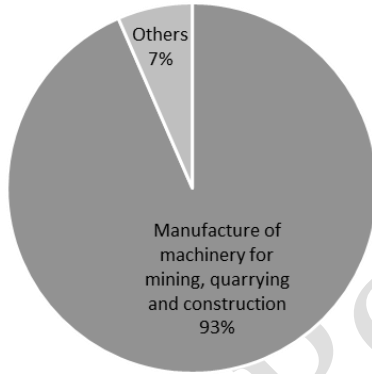
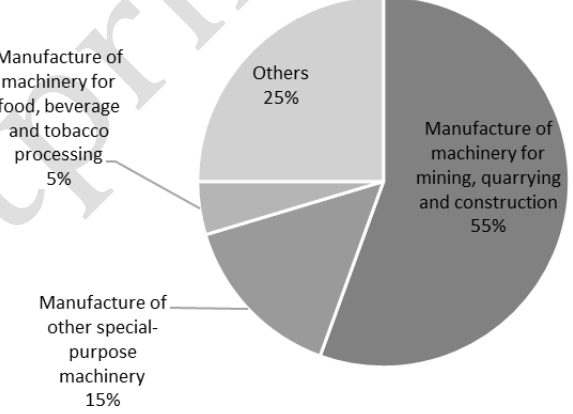
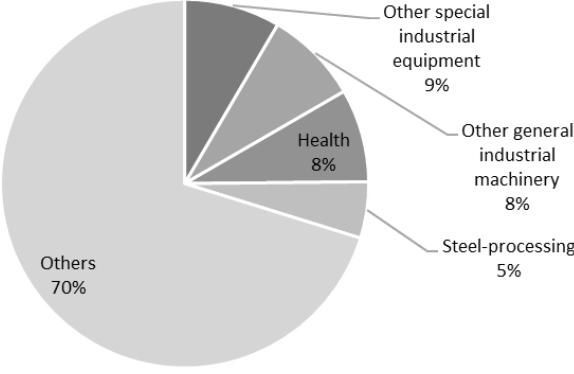
1 due to a major flood that affected the country in May 2014 (CRED/UCLouvain, 2020). The other
2 contributing activities for these hotspots are quite equally distributed among countries and
3 industrial sectors, underlining the complexity of the system's supply chain.

4 Finally, opportunities linked to 'contribution to economic development' are primarily occurring
5 in services sectors in BiH such as 'education, health and other services' (32%) or 'public
6 administration' (23%). The contribution of these two sectors to this subcategory can be explained
7 by two facts: firstly both activities are largely present in the background system in terms of
8 economic exchanges (relatively large consumption of these services by the primary and the
9 secondary sectors in BiH, according to the PSILCA database supported by EORA data) and
10 secondly their opportunity 'contribution of the sector to the economic development' level is
11 qualified as high (in the PSILCA database). It has to be noted that, in PSILCA, this indicators is
12 rated based on the different economic sectors contribution to the national GDP. Data were
13 accordingly derived from the United Nations statistics division (UNSTAT - Eisfeldt and Ciroth,
14 2017). For BiH, UNSTAT provides data for sectors aggregated in six main categories, while in
15 PSILCA, BiH economic activities are represented considering 26 sectors. Data used for the sectors
16 'education, health and other services' and 'public administration' are therefore not directly
17 representative of these two sectors but are proxies, potentially implying large uncertainty in the
18 accounting of their contribution. Finally, as mentioned in Table 4, there is a gap between the first
19 and second (here China) ranked countries where the most impactful activities occur, showing that
20 if one third of the opportunities are distributing worldwide, two thirds occur locally in BiH.

21 3.2. Sensitivity assessments

22 The production of lead concentrate in Olovo as modeled here is just a single pilot case study. At
23 term, the MMP is expected to be highly versatile, and to be adapted (through unit operations and
24 flowsheet adaptation) to exploit several type of ores throughout Europe. To test the sensitivity of
25 the hotspots assessment and its interpretation to 1) a different renewable electricity generation
26 system and 2) a different location of the MMP operation, two sensitivity analyses are performed.
27 The first comprises of switching the source of electricity in the system from a diesel-driven
28 generator to a renewable electricity generation system. This switch globally enables a reduction
29 in environmental impacts regarding most impact categories, despite some trade-offs (Beylot et al.,
30 2020), and the potential social implications it may have are further investigated in the following.
31 The second examines the variability of the results as a function of the location (country) of
32 operation of the MMP, in a context where the future development and widespread use of the SOSO
33 mining approach is envisaged all across Europe.

Table 4 : Countries and activities contributions to some of the hotspots assessed in Figure 3

Contribution to environmental load	Social responsibility along the supply chain	Contribution to economic development
<p>BiH's contribution: 60%</p>  <p>Petroleum, chemical and non-metallic mineral products 52%</p> <p>Education, health and other services 29%</p> <p>Electricity by diesel generator on mine site 9%</p> <p>Others 10%</p>	<p>BiH's contribution: 65%</p>  <p>Foreground system 50%</p> <p>Petroleum, chemical and non-metallic mineral products 13%</p> <p>Maintenance and repair 9%</p> <p>Education, health and other services 7%</p> <p>Others 21%</p>	<p>BiH's contribution: 62%</p>  <p>Education, health and other services 32%</p> <p>Public administration 22%</p> <p>Foreground system 22%</p> <p>Financial intermediation and business activities 8%</p> <p>Others 16%</p>
<p>United Kingdom's contribution: 27%</p>  <p>Manufacture of machinery for mining, quarrying and construction 93%</p> <p>Others 7%</p>	<p>United Kingdom's contribution: 16%</p>  <p>Manufacture of machinery for mining, quarrying and construction 55%</p> <p>Manufacture of other special-purpose machinery 15%</p> <p>Manufacture of machinery for food, beverage and tobacco processing 5%</p> <p>Others 25%</p>	<p>China's contribution: 10%</p>  <p>Health 8%</p> <p>Other special industrial equipment 9%</p> <p>Other general industrial machinery 8%</p> <p>Steel-processing 5%</p> <p>Others 70%</p>
Other countries contribution: 13%	Other countries contribution: 19%	Other countries contribution: 28%

3.2.1. Switching to a renewable source of energy

In the frame of the project, the most performant renewable electricity production system for the Olovo region has been defined using cost optimization techniques (Paneri 2019; Paneri and Yan 2020). The defined system consists of an electricity mix based on 35% of biomass energy using woodchips as fuel and on 65% electricity generated by photovoltaic panels. To perform the sensitivity assessment, the unit operation 'electricity supply' is redefined to consider this mix. The supporting information document provides the description of this 'renewable electricity supply' unit operation consisting of photovoltaic panels and a generator running on biomass (fed with woodchips), combined with batteries and a converter; as well as the associated quantified exchanges and social indicators. The production of these different components is approximated by industrial activities modeled in the PSILCA database. Their quantification in monetary units are derived from the data used to perform the cost optimization (Paneri and Yan, 2020). The social and socio-economic indicators associated with the 'renewable electricity production' are the same as those associated with the 'electricity production through the diesel generator' except for the 'Safe and healthy living conditions' for the local community stakeholder group, where the contribution of the electricity supply to the environmental load are redefined to consider the direct air emissions of the renewable energy production system. Finally, and as for the original unit operation, the activity variable is defined based on the ones used in PSILCA for the 'Biodiesel electricity generation, UK' and 'Photovoltaic electricity generation, UK' as these are the only proxies available in PSILCA. All values and associated assumptions and data sources are available in the supporting information document.

As shown in Figure 4, switching the system's energy supply from a diesel generator to a renewable source increases the overall impact by 5%. In total, 27 risks indicators (out of 39) show a greater value in the case of the renewable energy system. Concerning the main hotspots, only the order of the associated hotspots changes. If the hotspot 'contribution to environmental load' remains the principal, it is reduced to 15% compared to the initial system. In particular, the manufacture of mining equipment in the United Kingdom and the direct emissions in the United States associated to the production of the batteries are primary contributors, leading to off-site (and off-BiH) impacts. The figure available in the supporting information document shows that out of the 27 indicators that are greater in the case of the system running on renewable electricity, five are twice as important as in the initial system ('Indigenous rights', 'Minerals consumption', 'Association and bargaining rights', 'International migrant stock' and 'Biomass consumption'). These occur outside of BiH in countries participating in the value chain of the renewable energy system components (mainly in Australia and the United States where the photovoltaic panels and the batteries are respectively produced) as well as in the United Kingdom where the mining equipment are mainly manufactured. Demonstrating the supply chain complexity, the risks

1 associated with 'association and bargaining rights' occurs mainly in China and those associated
2 with 'biomass consumption' in India (due to its trade links with Australia). The exploitation of
3 woodchips in Bosnia to feed the biomass generator contributes to less than 1% to this risk, a more
4 precise investigation of the woodchips supply is needed to confirm this figure. Concerning the
5 social opportunity 'contribution to economic development', powering the system using renewable
6 energy gives a 5% greater score than the initial system. Contrary to the initial system where over
7 60% of the opportunity occurs in BiH (foreground country of lead concentrate production), here
8 only 14% occurs in BiH and therefore with the majority occurring in the rest of the world, for
9 example in China where activities contribute to 25% of this opportunity. These activities are
10 mainly involved in the supply chains of the different electronics equipment used for the renewable
11 electricity infrastructure.

12 Finally, it is to be noted that the renewable energy system produces excess electricity (34% that
13 is not used in the plant nor valorized on the grid). Reducing or using this excess electricity offers
14 an opportunity to reduce the social risks associated to the whole system.

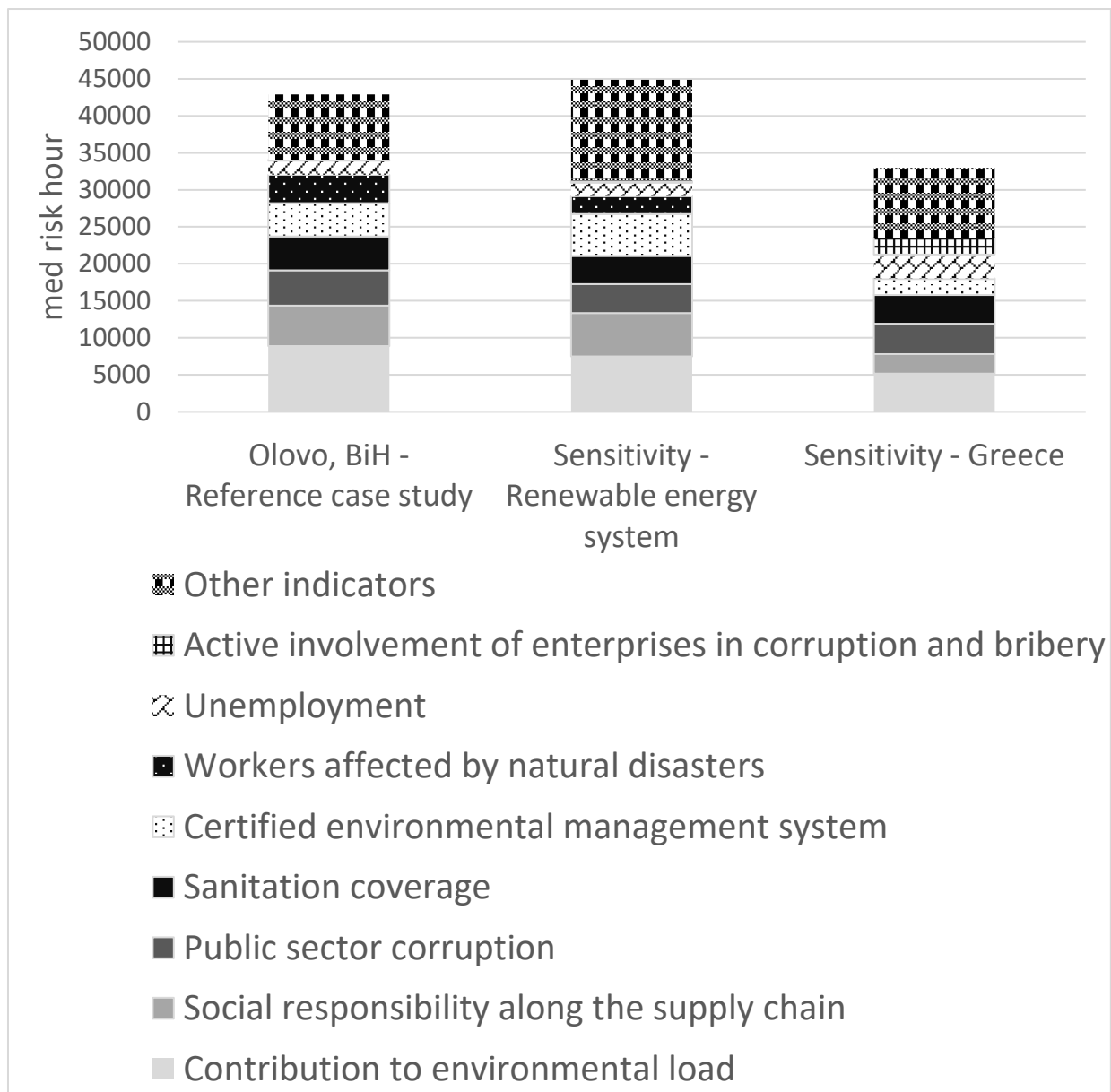


Figure 4: Hotspots representation of the three assessed case studies – The hotspots were chosen to represent at least 70% of the overall impacts

3.2.2. Switching to another country of operation

As the MMP is expected to be highly versatile and the unit operations will be adapted to exploit whatever type of mineral ores, the sensitivity scenario regarding the location has been defined considering two conditions: 1) the same type of ore deposit (i.e. cerussite) should be potentially exploitable in order to consider the same lead concentrate production flowsheet and; 2) the country should differ from Bosnia and Herzegovina in terms of development level (using the human development index). Using the ProMine database (<http://promine.gtk.fi/index.php>) (Cassard *et al.*, 2015), Greece is identified as the host of a potential ore deposit. Moreover, Greece is rated 32nd in the human development index, with Bosnia and Herzegovina 75th.

In order to adapt the product system to an operation in Greece, the following steps are considered. In a first step, the PSILCA activities used to model the foreground system is switched to Greek activities to consider the specific context of the country. In terms of social indicators defined to model the foreground unit operations, the ones quantified for the 'Mining of ore and concentrate, GR' are taken into account and adapted to the MMP context. For that, the following modifications are made: the indicators linked to the category 'Health and safety' for the workers stakeholder group and the 'Safe and healthy living conditions' for the local community stakeholder group where modified to consider the direct air emissions of the MMP operations as defined in Table 2. The supporting information document provides all information linked to these assumptions.

When switching the country of operation from BiH to Greece the overall impacts decrease of almost 30%, Figure 4 shows that moreover two hotspots differ. 'Unemployment' and 'active involvement of enterprise in corruption and bribery' are two hotspots identified in the Greek context whereas 'certified environmental management system' is about half the value of the Bosnian case and 'workers affected by natural disasters' represents only 2% of the value linked to the Bosnian case.

For the 'unemployment' risk indicator, the foreground is both qualified as 'very high risk' for the Greek and the Bosnian case studies; in the PSILCA v2 database, Bosnian activities are not rated for this indicator as well as for the 'active involvement of enterprises in corruption and bribery' indicator due to lack of data. Since the release of PSILCA v2, ILOSTAT (source used by the creators of PSILCA to rate the 'unemployment' indicator) has released statistics for BiH for the PSILCA year of reference (2016). The Bosnian unemployment rate at this time was of 22.3% (against 23.7% in Greece) (International Labour Organisation, 2020). This assessment indicates that the 'unemployment' risk may be higher in the initial case study because 47% of economic exchanges within the initial system are occurring in BiH (against 54% in Greece in this sensitivity case study). Concerning the 'active involvement of enterprises in corruption and bribery', 93% of the potential risk occurs in Greece where foreground activities are rated as 'very high risk'. The rating in PSILCA v2 is based on OECD data classifying foreign bribery enforcement actions by industrial activities. This data is intended to be applicable to the OECD members and 7 other countries (BiH not being one of them, there is no data and so risk associated to this indicator for the activities occurring in the country) and demonstrates that the extractive sector is most affected by enforcement actions (Eisfeldt and Ciroth, 2017). Public corruption is also known to be occurring in BiH (the indicator is rated as 'very high risk' in PSILCA v2, and it is ranked 89 (out of 180 countries) at the Transparency international index. Moreover, greater effort to combat corruption is a precondition to the country obtaining access to the EU (Lee-Jones, 2018), as a 2013 report by the United Nations showed that almost 10% of Bosnian companies had paid a bribe to public officials,

but the practice of business-to-business bribery seems inexistent (UNODC, 2013). So, this 'active involvement of enterprises in corruption and bribery' risk may be overestimated in the Bosnian case study.

Finally, Figure 4 shows that the overall Greek impacts are less than those of the initial case study. Differences between impacts in the Greek case and the initial case study are particularly important for the indicators 'workers affected by natural disasters', 'child labor', 'fair salary', 'certified environmental management system', 'contribution to environmental load', 'safety measures' and 'education' for which Greek impacts represent less than 80% of Bosnian impacts. For the indicator 'workers affected by natural disasters', the variation can be explained by the difference in ratings (as 'very low risk in the Greek foreground and as 'very high risk' in the Bosnian, see section 3.1 and the supporting information document). For the indicators 'contribution to environmental load' and 'safety measures', the scores in the foreground are the same in both the Bosnian and Greek cases; the variation here is due to the difference in ratings upstream in the value chain; and especially in the upstream chain occurring in the country of operation. In the Greek case, contribution of activities occurring in Greece is lower than the contribution of activities occurring in BiH in the Bosnian case. An explanation for the other indicators might lay in the discrepancies between both countries' development level of their mining sectors. As member of the EU, Greece is subject to the specific European regulations linked to the extractive industries. In addition, the European Bank for Reconstruction and Development rates Greece with a higher resource potential and stronger business environment for mining than BiH (2017). In both countries, while mining represents almost 2% of their respective GDP (European Bank for Reconstruction and Development, 2017; Trading Economics, 2020), the Greek GDP is almost ten times greater than the Bosnian GDP while the GDP per capita is almost four times greater. Finally, in terms of human development, Greece and BiH are rated differentially in the human development index (see section 2.3.2.). The Human Index Development does not consider all aspects of human development – it addresses life expectancy, the level of education and the gross national income of each country (UNDP, 2019). It might so explain some discrepancies in hotspots such as 'Education' that is 25% greater when the system is operating in BiH.

4. Limits and Recommendations

4.1. Limits of the study

The study presented here suffers from some limits mainly due to modelling considerations and data quality. First of all, the foreground is entirely modeled based on a technical perspective. In other terms, economical flows in the foreground represent all flows of materials and energy; however economic flows representing exchanges with service activities are not here considered in the foreground. It might lead to potential underestimations of hotspots quantification as the

contribution to service activities such as 'Education, Health and Other Services' and 'Public Administration' occurring in BiH have a greater contribution in the hotspots assessed for the Mining and quarrying sector in BiH than in this product system (when looking at hotspots presented in Figure 4). This absence of consideration is due to the nature of the assessed operations, as, in this study, the MMP is operated on a pilot level. To run this operation, no specific corporate entity was created, workers deployed to run the system operation were coming from a local mining company. In this context, no specific exchanges with companies from the service sector was observed. The fact that the operation is run on a pilot level without specified corporate entity and without a specific business plan prevents also to adapt some social and socio-economic indicators to the context of the study. This is the case for indicators quantified based on specific measures that can be taken by the company operating the system under study. However, assessing potential impacts in the early stages of a project development allow to put in place, before widespread of the project, measures to mitigate these impacts.

A second main limit of this study is the level of data quality. Apart from economic exchanges in the foreground (see the Supporting information document for a complete list), some of the indicators that were adapted for the foreground (see Table 3) and activity variables for the foreground (see Table 1), all other elements are modeled and quantified using PSILCA v2.0 database. Using a generic database implies data representativeness issues on two levels. The first level is linked to the modelling of economic exchanges based on the EORA multi-regional database in PSILCA. In EORA, intercountry and intersector economic exchanges are modeled based mainly on national statistics and international trade data but also on some specific modelling assumptions. In the database, economic sectors of 187 countries are modeled, however national statistics were used in the construction of EORA only for 74 countries. Data for missing countries are based on proxies built on information from four countries (Australia, United States, United Kingdom and Japan, Lenzen et al. 2012). A second level regarding data representativeness issues is linked to the quantification and therefore to the risk level definition of the social and socio-economic indicators in the PSILCA database. This quantification is here also mainly based on international statistics that can be country specific (such as for 'child labor' or 'frequency of forced labor'), sector specific (such as 'active involvement of enterprises in corruption and bribery') or both country and sector specific (such as 'international migrant workers in the sector'). Furthermore, for some countries and/or sectors no data are available in the international statistics sources. In this last case, PSILCA assigns a risk factor of 0.1 that is equivalent to a risk level 'low risk'. This can lead to potential risk under- or overestimation depending on the assessed sector and/or country. Overall, to enhance the reliability of this social hotspot assessment, reliability of the data used should also be enhanced. The foreground modelling is based both on on-site information completed with generic information either coming from literature sources or PSILCA database; the background system is

modeled using a generic database. Uncertainties linked to the use of generic data propagate to the results of this case study. Despite these main limits, the study provides a holistic vision of potential social hotspots of the system, hotspots that can be followed and for which specific recommendations can be given.

4.2. Recommendations for SOSO mining development

This social hotspot assessment has been conducted during the development at pilot-scale of the SOSO mining approach. In particular, no specific business plan or management structure was defined at that point of time, thus allowing the opportunity to implement the most appropriate mitigation measures to reduce the potential social risks. As seen in section 3.1, the foreground's contribution to a majority of the hotspots is quite important. For some of them, the management structure put in place will have a major role in handling these risks. This is particularly the case for the hotspots 'social responsibility along the supply chain', 'public sector corruption' and 'certified environmental management systems' that depend directly, in the PSILCA database, on initiatives put in place by the mining operator to promote CSR and environmental, social and governance (ESG). As stated by several authors (see for example Mutti *et al*, 2012; Devenin and Bianchi, 2018), CSR initiatives are not always positively perceived by the local community. The IMPaCT project investigated specifically the social acceptance of SOSO mining and provided policy guidance linked to CSR in the small-scale sector particularly (Sydd, Sairinen, *et al.*, 2020).

Concerning the hotspot 'contribution to environmental load', this social assessment provides only an incomplete environmental assessment. Beylot *et al.* conducted an environmental LCA on the same system and showed that environmental impacts are driven by electricity demand and supply, equipment production and potentially tailings management (2020). The renewable electricity supply scenario, despite producing 34% of excess electricity, had a better potential environmental profile for eight environmental impact categories out of thirteen as shown by Beylot *et al.* (2020). However, the sensitivity analysis showed that switching to renewable electricity supply source may lead to greater potential social risks primarily due to the increased complexity of the supply chain (for more than two thirds of the assessed social indicators, more than 90% of the potential social risks occur outside BiH). The various conclusions arising from the sensitivity analysis conducted in both the environmental and social LCA shows the importance of conducting a multi-criteria assessment considering all dimensions (environmental, social and economic) in order to comprehensively and accurately inform the decision makers.

The hotspot 'Workers affected by natural disasters' is not directly linked to actions made by the business owner or the mine operator as it represents risks linked to natural hazards (see section 3.1). Specific measures can be taken at the company level to limit risks linked to natural hazards (such as adopting natural risks prevention plans or emergency plans). Effectively, natural hazards

can have effects not only on the workers stakeholder category but also on the local community. In fact, for example, tailings spills and tailings dam failures often occur due to specific climatic conditions (precipitation on sulfidic material contain in the tailings can provoke metal leaching in the surrounding environment) or due to natural hazards such as the ones considered in the 'Workers affected by natural disasters' hotspot (heavy rainfall, flash flooding or earthquakes can instigate tailings dam failures, leading to severe impacts on humans and the ecosystem) (Broadhurst and Petrie, 2010; Kossoff *et al*, 2014). Some legacy tailings facilities remain at risk of spillage and dam failures well after mine closure, which may cause problems for the local community. Therefore, tailings management and mine closure planning should be carefully considered in the early stages of the project development. Depending on the business plans created for SOSO mining development, different options may be considered, such as on-site tailings management, construction of a central site to manage tailings produced from different SOSO mine sites, or transportation to existing tailings management facilities. However, the economic, social and environmental implications for each of these options should be assessed based on the local context.

4.3. SOSO mining issues not considered in this study

The mining sector has both positive and negative impacts on the environment and the society. Performing a social hotspot assessment using S-LCA databases and their associated indicators does not allow identification of all social issues associated to the mining sector and in particular the small scale SOSO mining sector. In the frame of IMPaCT, Sidorenko et al. conducted a census of potential social impacts associated with the development of SSM in Europe (2020 ; Sairinen, Sidorenko and Tiainen, 2021). Some of them also applied to SOSO mining and are related to various issues, both positive and negative, that are not assessed in the S-LCA.

The first being the temporal perspective associated with deposit exploitation using SOSO mining. If the exploitation period of a large scale mine might be several decades, the anticipated duration in the SOSO context varies from several months to several years. Furthermore, the SOSO paradigm allows the rapid start and stop of the exploitation depending on metal prices (e.g. with the SOSO concept, an exploitation can quickly be stopped if no longer economically sustainable). This aspect leads to some discrepancies with traditional mining operations. The first discrepancy is linked to the mine's contribution to the overall economy of the region, the diversification of a region's industrial activities (implementation of subcontractors or services industries for example) and to infrastructure development in general. In the case of SOSO mining, this contribution to regional industrial development may be limited. One of the few contributions to the regional economic development might be linked to tax payment. This question of short temporality also affects the sustainability of employment, and the business plans that will be

developed to operate the MMP in the frame of the SOSO concept will play a significant role on local employment. In fact, the MMP might either be run by people from the local workforce with a non-permanent contract or by people with a permanent contract that will move with the MMP depending on the deployment strategy.

A second issue is linked to the spatial footprint associated with SOSO mining, which can occupy a smaller area of land than traditional mining. Having a smaller footprint and developing protocols to treat the remaining mining wastes (see previous section) will reduce the risks associated with mine closure (such as job losses and post-closure governance & environmental risks, see for example Bainton and Holcombe, 2018) and encourage post-mining heritage for the local community. In fact, a smaller footprint might also imply the presence of less and less heavy infrastructures meaning a smaller influence of the operations on the landscape would additionally potentially lead to an easier way to re-affect the mine site to different purposes after mining operations. This minimization is possible as long as MMP operations do not occur simultaneously in a relatively small area.

A third issue is linked to the modularity of the MMP per se. Given its characteristics of interoperability and rapid deployment, MMPs can also serve as a tool to perform prefeasibility studies on specific mine sites as well as small-scale containerized processing, on a pilot scale. MMP can also serve to train the local workforce to operate the MMP, which can then be applied to future mining sites being operated using the same unit processes. This can minimize the economic risks associated with the commencement of mining operations, particularly by accelerating the time dedicated on workforce training.

A final stake is linked to the purpose of SOSO mining itself. The concept was created in order to unlock the access to CRMs in Europe for the benefit of the EU, which can reduce the supply risk associated with these materials. Ensuring a secure, sustainable supply of CRMs to the European manufacturing industry is crucial for the wider economic development of the EU, and also for the deployment of technologies for the green energy transition.

In order to specifically assess these issues, first representative indicators should be defined and quantified. This task was outside the scope of the presented study.

5. Conclusion

This social hotspot assessment using the PSILCA database is performed on a pilot scale operation of the MMP developed in the frame of the IMPaCT project, which has aimed to establish a new small scale SOSO mining paradigm. The study considers the context of the project by taking into account the relevant socio-economic indicators for the mining sector in BiH and more particularly

1 in Olovo. Moreover, the foreground is modelled to consider on-site specific data obtained through
2 interviews with the MMP operators (regarding the indicators referring to the “Workers”
3 stakeholder group) and E-LCA results (regarding mainly emissions to environment).

4 Alongside the environmental evaluation performed on the same product system (Beylot *et al*,
5 2020), the objective of this study is to provide recommendations for the deployment of the SOSO
6 approach on a broader scale. Despite the limits identified in the modelling choices and in the data
7 representativeness, it still provides information for the equipment manufacturers and the MMP
8 operators concerning the specific hotspots that need to be addressed during the more extensive
9 deployment of the SOSO mining system. One type of uncertainty is directly linked to data
10 availability and updating in the PSILCA database: some risks are not rated for BiH (such as
11 ‘unemployment’ for example) leading to potential underestimation of some hotspots. Finally, it is
12 important to bear in mind the specific social preoccupations of the various stakeholders (such as
13 the local community and the workers) as well as the issues related to the mining sector that are
14 not considered in the S-LCA framework (such as the temporal perspective or land use).

15 Once the MMP and the SOSO paradigm are deployed on a broader scale, it is recommended to
16 perform a second S-LCA based on this one which takes into consideration the specificities of the
17 operating company and its business plan in order to identify the remaining social pitfalls.

18 Measurement of the potential social and environmental sustainability performances of existing
19 projects can also be used for communication with stakeholders regarding future developments.
20 Sharing results linked to social and environmental concerns of the local community may help
21 developing trust and stakeholder engagement vis-a-vis the project that is one of the key to the
22 social license to operate. Acquiring the “social license to operate” from the local community in the
23 mining sector is crucial in order to pursue the project.

24 Finally, from a broader perspective, metals and mineral raw materials are entering various
25 product systems in different industrial sectors. Understanding their social implications helps with
26 understanding the social implications of the system they are part of. In particular in a context
27 where industries are expected to communicate on their environmental and social responsibility.
28 Both the qualification and quantification of social impacts can also be used in the assessment of
29 sustainable procurement policies which are implemented by companies or countries extracting
30 raw materials specifically.

31

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