Can S-LCA methodology support responsible sourcing of raw materials in EU policy context?

S.; Siemiarczuk, T.; Silva, T. F.; Silvermyr, D.; Simantathammakul, T.; Simeonov, R.; Singh, B.; Singh, B.; Singh, K.; Singh, R.; Singh, R.; Singh, R.; Singh, S.; Singh, V. K.; Singhal, V.; Sinha, T.; Sitar, B.; Sitta, M.; Skaali, T. B.; Skorodumovs, G.; Slupecki, M.; Smirnov, N.; Snellings, R. J. M.; Solheim, E. H.; Song, J.; Sonnabend, C.; Sonneveld, J. M.; Soramel, F.; Soto-hernandez, A. B.; Spijkers, R.; Sputowska, I.; Staa, J.; Stachel, J.; Stan, I.; Steffanic, P. J.; Stiefelmaier, S. F.; Stocco, D.; Storehaug, I.; Stratmann, P.; Strazzi, S.; Sturniolo, A.; Stylianidis, C. P.; Suaide, A. A. P.; Suire, C.; Sukhanov, M.; Suljic, M.; Sultanov, R.; Sumberia, V.; Sumowidagdo, S.; Szarka, I.; Szymkowski, M.; Taghavi, S. F.; Taillepied, G.; Takahashi, J.; Tambave, G. J.; Tang, S.; Tang, Z.; Tapia Takaki, J. D.; Tapus, N.; Tarasovicova, L. A.; Tarzila, M. G.; Tassielli, G. F.; Tauro, A.; Tavira García, A.; Tejeda Muñoz, G.; Telesca, A.; Terlizzi, L.; Terrevoli, C.; Thakur, S.; Thomas, D.; Tikhonov, A.; Tiltmann, N.; Timmins, A. R.; Tkacik, M.; Tkacik, T.; Toia, A.; Tokumoto, R.; Tomohiro, K.; Topilskaya, N.; Toppi, M.; Tork, T.; Torres, V. V.; Ramos, A. G. Torres; Trifiró, A.; Triolo, A. S.; Tripathy, S.; Tripathy, T.; Trogolo, S.; Trubnikov, V.; Trzaska, W. H.; Trzcinski, T. P.; Tumkin, A.; Turrisi, R.; Tveter, T. S.; Ullaland, K.; Ulukutlu, B.; Uras, A.; Urioni, M.; Usai, G. L.; Vala, M.; Valle, N.; Van Doremalen, L. V. R.; Van Leeuwen, M.; Van Veen, C. A.; Van Weelden, R. J. G.; Vande Vyvre, P.; Varga, D.; Varga, Z.; Torres, P. Vargas; Vasileiou, M.; Vasiliev, A.; Vázquez Doce, O.; Vazquez Rueda, O.; Vechernin, V.; Vercellin, E.; Vergara Limón, S.; Verma, R.; Vermunt, L.; Vértesi, R.; Verweij, M.; Vickovic, L.; Vilakazi, Z.; Villalobos Baillie, O.; Villani, A.; Vinogradov, A.; Virgili, T.; Virta, M. M. O.; Vislavicius, V.; Vodopyanov, A.; Volkel, B.; Völkl, M. A.; Voloshin, S. A.; Volpe, G.; Von Haller, B.; Vorobyev, I.; Vozniuk, N.; Vrláková, J.; Wan, J.; Wang, C.; Wang, D.; Wang, Y.; Wang, Y.; Wegrzynek, A.; Weiglhofer, F. T.; Wenzel, S. C.; Wessels, J. P.; Wiechula, J.; Wikne, J.; Wilk, G.; Wilkinson, J.; Willems, G. A.; Windelband, B.; Winn, M.; Wright, J. R.; Wu, W.; Wu, Y.; Xiong, Z.; Xu, R.; Yadav, A.; Yadav, A. K.; Yalcin, S.; Yamaguchi, Y.; Yang, S.; Yano, S.; Yeats, E. R.; Yin, Z.; Yoo, I. -K.; Yoon, J. H.; Yu, H.; Yuan, S.; Yuncu, A.; Zaccolo, V.; Zampolli, C.; Zanone, F.; Zardoshti, N.; Zarochentsev, A.; Závada, P.; Zaviyalov, N.; Zhalov, M.; Zhang, B.; Zhang, C.; Zhang, L.; Zhang, M.; Zhang, S.; Zhang, X.; Zhang, Y.; Zhang, Z.; Zhao, M.; Zherebchevskii, V.; Zhi, Y.; Zhong, C.; Zhou, D.; Zhou, Y.; Zhu, J.; Zhu, Y.; Zugravel, S. C.; Zurlo, N.. - In: EUROPEAN PHYSICAL JOURNAL. C, PARTICLES AND FIELDS. - ISSN 1434-6052. - STAMPA. - 85:2(2025). [10.1140/epjc/s10052-025-13793-y]

Can S-LCA methodology support responsible sourcing of raw materials in EU policy context?

Claudia Di Noi[1, *], Andreas Ciroth[1], Lucia Mancini[2],

Umberto Eynard[2], David Pennington[2], Gian Andrea Blengini[2]

1 GreenDelta GmbH, Müllerstrasse 135, 13349 Berlin, Germany

2 Joint Research Centre, via E. Fermi 2749, I-21027 Ispra (VA), Italy

*Claudia Di Noi, dinoi@greendelta.com Tel. +49 30 44 327 - 507 | Fax +49 30 48 496 - 991

Abstract

Purpose Access, affordability, and sustainability of raw materials supply chains are crucial to the sustainable development of the European Union (EU) for both society and economy. The study investigates whether and how the Social Life Cycle Assessment (S-LCA) methodology can support responsible sourcing of raw materials in Europe. The potential of social indicators already available in an S-LCA database is tested for the development of new metrics to monitor social risks in raw materials industries at EU policy level.

Methods The Product Social Impact Life Cycle Assessment (PSILCA) database was identified as a data and indicators source to assess social risks in raw materials industries in EU-28 and extra-EU countries. Six raw materials country-sectors in the scope of the European policy on raw materials were identified and aggregated among those available in PSILCA. The selection of indicators for the assessment was based on the RACER (Relevance, Acceptance, Credibility, Ease, Robustness) analysis, leading to the proposal of 9 social impact categories. An S-LCA of the selected raw materials industries was, thus, performed for the EU-28 region, followed by a contribution analysis to detect direct and indirect impacts and investigate related supply chains. Finally, the social performance of raw materials sectors in EU-28 was compared with that of six extra-EU countries.

Results and discussion Considering the overall social risks in raw materials industries, “Corruption”, “Fair salary”, “Health and safety”, and “Freedom of association and collective bargaining” emerged as the most significant categories both in EU and extra-EU. EU-28 shows an above-average performance where the only exception is represented by the mining and quarrying sector. An investigation of the most contributing processes to social impact categories for EU-28 led to the identification of important risks originating in the supply chain and in extra-EU areas. Therefore, the S-LCA methodology confirmed the potential of a life cycle perspective to detect burdens shifting and trade-offs. However, only a limited view on the sectoral social performance could be

obtained from the research due to a lack of social data.

Conclusions The S-LCA methodology and indicators appear appropriate to perform an initial social sustainability screening, thus enabling the identification of hotspots in raw materials supply chains and the prioritization of areas of action in EU policies. Further methodological developments in the S-LCA field are necessary to make the approach proposed in the paper fully adequate to support EU policies on raw materials.

Keywords *raw materials, S-LCA, social risk, supply chain, criticality, indicator*

1. Introduction

1.1. EU Policy context

The European Union (EU) was founded on fairness and essential values, including sustainable development and social inclusion as fundamental objectives (EC - European Commission 2018; 2016; 2015). Current EU policies and initiatives (EC – European Commission 2016; Mancini et al. 2018) contribute to the 2030 Agenda for Sustainable Development and the Sustainable Development Goals (SDGs). The SDGs directly and indirectly tackle social issues, which are often responsible for political conflicts and impediments to an inclusive social and economic development. The EU has shown its support for the principles of social fairness and inclusion with the proclamation of the European Pillar of Social Rights (EC – European Commission 2018). In parallel, the impact of businesses on society has emerged as a fundamental issue, leading to the concepts of Corporate Social Responsibility (CSR) and -more recently- Business to Society (B2S), as one aspect of CSR. With the B2S approach, companies have the chance to go beyond a fair and sustainable social performance and, hence, can create value for the society by contributing to its advancement (Frost & Sullivan 2014). The EU encourages CSR and B2S in the framework of the 8th goal of SDGs, namely "Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all". In fact, through integration of social and environmental attention in business, companies contribute to better chances for sustainable growth and employment conditions (EC – European Commission 2017). Furthermore, social responsibility in business practices is becoming more relevant, considering that several enterprises invest in developing countries or may import raw materials from high-risk and conflict-affected areas (EU- European Union 2017). Most notably, social risks in raw materials supply chains have emerged as a major concern in recent years. The responsible sourcing of raw materials, together with their secure access and affordability, are fundamental issues for a sustainable development of the EU both for society and economy. European countries highly depend on imports of raw materials from non-EU Countries, such as China, South Africa, Russia, and Australia. (Blengini et al.

2017). Therefore, a continuous threat of a supply crisis is posed to the EU due to this dependence and a lack of alternative materials.

In order to address the multiple challenges imposed by the sustainable sourcing of raw materials, the European Commission (EC) launched the Raw Materials Initiative (RMI) in 2008. The initiative takes action in the framework of non-agricultural, non-energy raw materials and is based on three main pillars: (1) access to a sustainable and fair supply of raw materials from global markets; (2) sustainable conditions within the EU for the use of European sources to supply raw materials; (3) promotion of recycling to ensure resource efficiency, increasing secondary raw material supply, and reducing import dependence from non-EU countries. One of the priorities of the RMI is the identification of Critical Raw Materials (CRM), i.e. raw materials crucial to Europe because of their economic importance and high supply risk. Due to their technical and economic recycling potential, CRM are crucial to the Circular Economy strategy which promotes the use of secondary raw materials (EC – European Commission 2018). According to the Guidelines for establishing the EU list of CRM (EC – European Commission 2017), the economic importance and governance performance of resource producing countries are amongst the parameters to calculate the supply risk of materials. In addition, the governance situation of a country may affect the complex system of interconnected social issues which are often associated with raw materials supply chains, such as working conditions and local communities´ vulnerability. In this framework, the EU has acted to support transparency in raw materials sourcing, especially in the case of imports from conflict-affected areas. The EU Regulation on Conflict Minerals (EU – European Union 2017) attempts to break the bond between conflicts and resources to prevent armed groups from being financed with earnings from illegal trade of materials. The international reference in this field is the OECD Guidance which aims at helping companies in undertaking due diligence in minerals supply chains (OECD 2016).

In order to efficiently implement the objectives outlined in the RMI, the European Innovation Partnership (EIP) on Raw Materials was established in 2012. The EIP promotes collaboration between different stakeholders (EU, industries, institutions, academia, and NGOs) to achieve the targets set by the EU policy framework on raw materials. As a monitoring scheme as well as a source of quantitative data for the EIP, the Raw Materials Scoreboard (RMS) was first published in 2016 and updated in 2018 (EC – European Commission 2016; 2018). The current version of the RMS contains 26 indicators, with only two of them ("Occupational safety" and "Sustainability reporting") referring to social sustainability. Therefore, the discussion and development of metrics to quantify social issues in raw materials production are crucial to enhance the sustainability of the sector.

1.2. Motivation

The present study arose in the context of the update of the first edition of the RMS in the end of 2017 with the objective of defining new metrics for monitoring the sustainability of the raw materials sector. For this purpose, the main interest was the assessment of social sustainability performance of EU and extra-EU raw materials industries and how this could be done in terms of tools and methodologies. Indeed, social risks connected to the production of raw materials should be assessed in order to seek a socially sustainable supply both from EU and extra-EU sources. International resources trade may shift social burdens into countries with poorer regulations, even though EU has a well-established law context on social rights and working conditions (European Labour Law, EU Occupational Safety and Health (OSH) Strategic Framework 2014-2020).

In the framework of this study, Life Cycle Thinking (LCT) tools can make an important contribution to the evaluation of the social sustainability of raw materials. Indeed, LCT tools have the capability to identify and measure impacts associated directly and indirectly (i.e. in the supply chain) to the sector under study and occurring in different geographic locations. Hence, a crucial role is played by Social Life Cycle Assessment (S-LCA), which is a methodology to assess social and socio-economic aspects of products together with positive and negative impacts, real or potential, along their life cycle (UNEP/SETAC 2009).

The research goals can be summarized as following.

- Identify social indicators in existing S-LCA databases as potential quantification metrics for monitoring social issues in the raw materials sector.
- Evaluate potentials and limitations of the S-LCA methodology to assess the social performance of the sector, with specific focus on supply chain risks.
- Investigate the potential contribution of the approach used in the study to support EU programmes and policies towards an increased social sustainability of raw materials, such as in the case of the RMS.

1.3. Current status of LCA in sustainability assessment of resources

"Resource criticality" has emerged as a major concern in policy and research contexts (Graedel et al. 2012; EC-European Commission 2010; Helbig et al. 2016) with an attempt to address economic importance and supply risks. In recent years, a number of studies have proposed the application of Life Cycle Assessment (LCA) to evaluate the impacts and the sustainability performance of the raw materials sector, highlighting the importance of considering the economic and geopolitical framework when conducting evaluations (Mancini et al. 2015; Sonnemann et al. 2015). Raw materials and CRM are already included as flows in inventories of most common databases. Furthermore, as Mancini et al. (2015) emphasise, available impact assessment methods currently consider some of the criticality aspects, such as resource scarcity and contribution to environmental load.

A recent debate has questioned whether related socio-economic issues should be addressed within environmental evaluations or social LCA (Mancini et al. 2015; 2013; Klinglmair et al. 2014). So far, environmental LCA approaches have been more inclined to evaluate the geophysical availability of materials (e.g. with the impact category "resource depletion") rather than to investigate the supply security and resource criticality, hence often excluding geo-political constraints. On the other hand, efforts were made to tackle resource security in sustainability assessment, investigating how this could be done in terms of methodology. For instance, Mancini et al. (2018) suggested the inclusion of the economic importance of resources in LCA by using characterization factors (CFs) to represent supply risk factors in Europe; in particular, the use of the ratio between supply risk and production data was proposed as CF to describe the size of the market and resource security impact in EU.

The present study aims at contributing to the outlined research context by exploring the S-LCA methodology for its potential to provide a set of socio-economic indicators useful to detect social issues in specific raw materials sectors.

2. Methods

2.1. Approach

The study applies the S-LCA methodology to evaluate social risks in selected raw materials industries in EU and extra-EU. The strengths and weaknesses of S-LCA to support a sustainable EU raw materials supply are presented and discussed in the article.

Risks were quantified with selected socio-economic indicators further grouped into impact categories. The first step of the work was choosing the S-LCA database for the assessment between the two currently available: Social Hotspots Database (SHDB) developed by New Earth and Product Social Impact Life Cycle Assessment (PSILCA) developed by GreenDelta. PSILCA was selected for the present study due to (1) more recent data sources, (2) presence of an evaluation schema for data quality, and (3) provision of transparent documentation on data sources and social risk levels. Once the database was defined, raw materials country-sectors and social indicators were identified and aggregated among those available in PSILCA, as described in sections 2.3 and 2.4. An S-LCA of six selected raw materials industries was then performed for the EU-28 region, followed by a contribution analysis to detect direct and indirect impacts and investigate related supply chains. Finally, the social performance of raw materials sectors in EU-28 was compared with that of six extra-EU countries to highlight common and different risk hotspots. Results are presented and discussed for 1 USD output per raw materials industry per region under study and include risks deriving from the upstream chain, such as supply sectors for energy, equipment, and construction materials. The software openLCA was used for performing the assessment; a cut-off criterion (1E-04) was applied to all calculations to be able to run them in an acceptable timeframe.

2.2. PSILCA database

PSILCA was identified as a data and indicators source to assess social risks in raw materials industries in different countries. PSILCA is a transparent database which uses Eora, a multi-regional input/output database, as a backbone to cover the world economy (Lenzen et al. 2012; 2013). Based on Eora, PSILCA contains comprehensive inventory information expressed as monetary exchanges for almost 15,000 industry sectors and commodities in 189 countries. Besides, it includes social indicators for several stakeholders, from workers to local community, society, consumers, and value chain actors. Regarding these indicators, data is provided as risks, with a scale ranging from no/very low risk to very high risk. A positive evaluation in terms of opportunities is also available. Social risks are quantified by the so-called activity variable, i.e. worker hours. Worker hours represent the time needed to produce 1 USD output of the sector. Social impacts of product systems are expressed in the case study as medium risk hour equivalents, which specify the observed indicator risk in worker hours related to its average (medium) risk to produce 1 USD output of the assessed sector. The resulting values per impact category are the sum of the individual indicator risk levels scaled by the price of the input sectors, the amount of worker hours of each process, and the characterization factors (CFs). CFs are provided in the database by the Social Impacts Weighting Method, which contains impact factors for each risk level per indicator (most commonly, CF very high risk=100; CF high risk=10; CF medium risk=1; CF low risk and no data=0.1; CF very low risk=0.01).

Regarding social data in PSILCA, most sources used in the database are obtained from recognized official statistical agencies, such as ILOstat, WHO and World Bank, and from other well-established public or private sources, such as ICTWSS and the World Factbook. Normalization was applied by the database provider for social data dependent on the size of the sector and country in order to allow comparisons across different countries and sectors.

2.3. Sector and country selection and aggregation

Considering that non-energy, non-agricultural sectors are in the scope of the European policy on raw materials outlined in Section 1.1, available national sectors in PSILCA were aggregated to reflect the following six biotic and abiotic raw materials industries in the different EU-28 countries:

- Mining and quarrying
- Manufacture of basic metals
- Manufacture of non-metallic mineral products
- Forestry and Logging
- Manufacture of paper and paper products (here called "Manufacture of paper")
- Manufacture of wood and of products of wood and cork, except furniture; manufacture of article of straw and plaiting materials (here called "Manufacture of wood")

Regarding EU-28, data needed to be aggregated both on regional and sectoral level to represent the selected industries in the EU-28 region. All PSILCA sectors of the 28 EU countries related to the previously chosen industries were aggregated in one "EU-28" process per raw materials sector. For this purpose, the PSILCA sectors were added as monetary inputs for 1 USD output (i.e. all inputs scaled to 1) per selected raw materials industry. In case of sectoral aggregation, Table 1 shows that input sectors were weighted equally within the countries (first factor in bold in the "Amount" column). In order to consider the contribution of the different countries to the European raw materials industry, the country specific share of the total EU production for each raw materials sector was taken into account and used as a weighting factor for regional aggregation (Eurostat 2017). This was realized with a parameter for each country, as shown by the second factor in the "Amount" column in Table 1.

In order to compare the social performance between EU and extra-EU areas, the six sectors were identified in PSILCA also for top raw materials producer countries (Reichl 2016) in five world regions (Asia, North America, Oceania, South America), beside EU-28. Specifically, China, Australia, USA, South Africa, Brazil, and Russian Federation. These countries are also among the main EU suppliers of CRM, therefore of strategic importance for the European security of supply. In the case of the extra-EU countries, only an aggregation on a sectoral level appeared necessary and was performed as already described for the European countries, i.e. available sectors in PSILCA were added on the input side (scaled to 1 and weighted equally) of six processes representing each of the six selected industries.

As no specific information was available in the database for "Forestry and Logging", "Manufacture of wood" and "Manufacture of non-metallic mineral products", data were selected from the "Manufacture of paper" sector for the first two industries and from "Manufacture of fabricated metal products, except machinery and equipment” for the latter. These substitutive sectors showed the best information in terms of completeness and suitability to replace the missing industries in the database. Regarding the “Mining and quarrying” sector, it was not possible to isolate the non-energy mining industry because social data in PSILCA are reported for the sector as whole, hence results of the study include the oil and gas sector as well.

2.4. Criteria for indicator and category selection

The selection of indicators and categories for the assessment was first based on the RACER analysis (Relevance, Acceptance, Credibility, Ease, Robustness of the indicator), already applied to other studies (Best et al. 2008). Additionally, this analysis was adapted and integrated with other criteria, including the indicator structure, data quality, and completeness in PSILCA. Table 2 shows the set of final criteria and sub-criteria used for the indicator selection.

The same weighting factor was assigned to all criteria and the total score for specific indicators was obtained by summing up the single scores for each sub-criterion. As a result, this approach led to the proposal of 9 impact categories and related indicators for the social sustainability assessment of raw material sectors in EU and extra-EU countries (see Table 3). Specifically, the following categories were identified.

- Health and Safety, which assesses workers´ well-being in relation to fatal and non-fatal accident rates, presence of sufficient safety measures, health damages due to a polluted working environment, and risk of natural disasters affecting workers.
- Freedom of association and collective bargaining, which refers to the workers´ right to assembly, protest, and strike.
- Child labour, which reports the risk of children ages 7 to 14 employed in economic activities.
- Fair salary, which assesses whether workers receive “a wage fairly and reasonably commensurate with the value of a particular service or class of service rendered” (UNEP/SETAC 2013), by considering the living wage in the country and the minimum and average wages in the sector.
- Working time, which reports the risk of improper (excessive or insufficient) working hours.
- Respect of indigenous rights, which is related to human rights issues faced by indigenous populations.
- Migration, which accounts for international migrants in a country and in different country economy sectors as well as for the net migration rate. This category may offer insights on risks of discrimination and potential social conflicts.
- Corruption, which assesses the risk that companies and /or the public sector are involved in corruption and bribery.

- Contribution to economic development, which evaluates the contribution of economy sectors to national GDP as well as the educational context of a country in relation to illiteracy rate and public expenditure on education.

When calculating results, indicators belonging to the same impact category are aggregated in order to obtain a single risk value. Within each category, indicators are given the same weighting factor. A full description of the indicators is available in the PSILCA manual (Eisfeldt 2017).

3. Results

Initially, the social performance of the selected industries was evaluated for the EU-28 region. Social risks in raw materials production, including the supply chain, were assessed using the indicators previously selected (see Table 3). Results show that the highest risks for all industries are associated with the impact categories "Corruption", "Fair salary", "Freedom of association and collective bargaining", and " Health and Safety", see Figure 1. As for the EU-28 raw materials sector performance, "Mining and quarrying" accounts for the highest risks in all the social categories considered, often with large differences from the other industries. Furthermore, when the social risks of the three biotic material sectors are analysed for EU-28, "Forestry and logging" generally displays a worse performance than "Manufacture of wood" and "Manufacture of paper", see Figure 2.

Following these first results, the contribution of direct and indirect impacts to the overall results was analysed to identify the share of risks associated with the sector itself (i.e. direct) and those originating from the upstream supply chain (i.e. indirect). The contribution analysis shows that the upstream chain is often accountable for social risks in EU-28 raw materials industries to a large extent. By analysing results for the mining and quarrying sector in more detail, it is possible to highlight that upstream processes in the supply chain contribute more than 90% to most impact categories, see Figure 3. When direct and indirect impacts are investigated for the other sectors, the supply chain contribution appears to be diminished in comparison with "Mining and quarrying". However, social risks deriving from upstream processes represent an important share in all categories, see for instance Figure 4 for "Forestry and logging".

Considering that the contribution of the supply chain to overall social risks emerged as an important finding, further reflections on the geographic distribution and main sources of risks along the upstream chain appeared necessary. A deeper investigation of the supply chain of different raw materials sectors in EU-28 shows that significant impacts are originating in extra-EU countries, specifically in Asian countries. For instance, Figure 5 shows that the main social hotspots related to the indicator "Freedom of associations and bargaining rights" for the sector “Forestry and Logging” in EU-28 are in China. In addition, India and a number of African countries often resulted as geographic locations for many social risks occurring in the upstream chain of EU-28 raw materials industries, for example in the case of the category “Fair salary” for the sector “Manufacture of basic metals” in EU-28, see Figure 6. Regarding the source of risks in the supply chains of the industries under study, it is possible to identify several recurring social hotspots between sectors and impact categories. Construction processes in India and China, basic metals and manufacturing in India, and metal products in China can be identified as the main contributing sectors to overall social risks in European raw materials industries. For instance, Table 4 shows that most of the top 10 impact contributions to “Fair salary” for “Mining and quarrying” in EU-28 originate in India and are associated with construction, manufacturing, and metals.

The selected indicators (see Table 3) were finally used to compare the social performance of raw materials industries between EU and extra-EU countries. Figure 7 reports social risks in raw materials sectors for EU-28 and the six selected extra-EU countries. Due to the sensitivity of the topic, country names are hidden in the figures and replaced with letters ranging from “A” to “F”. For most countries and social impact categories, “Mining and quarrying” and “Forestry and logging” often display a poorer social performance in comparison to the other sectors. Social risks within each sector were compared between EU-28 and extra-EU; for instance, Figure 8 displays a comparison of the overall social performance for the basic metals manufacturing sector in EU and extra-EU countries. Similar to EU-28, the highest risks for raw materials industries in extra-EU countries can be generally associated with the impact categories “Corruption”, “Fair salary”, “Freedom of association and collective bargaining”, and “ Health and Safety”. On the other hand, risks of excessive or insufficient working time are negligible for all regions. Furthermore, it is possible to identify country-specific social risk hotspots, i.e. social categories which emerged as significant only for some of the countries analysed, such as “Child labour” and “Respect of indigenous rights”.

Considering the overall social risks in raw materials industries in EU and extra-EU, EU-28 shows an above-average performance. This is particularly evident for “Forestry and Logging”, “Manufacture of non-metallic mineral products”, and “Manufacture of wood”, regarding the indicators “Freedom of association and bargaining rights”, “Corruption”, “Fair salary”, and “Respect of indigenous rights”. The only exception is represented by the mining and quarrying sector. In this case, results are similar to those for extra-EU developing countries with high risks in the categories “Migration”, “Corruption”, “Health and Safety”, “Working time”, and “Contribution to economic development”, see Figure 9.

In summary, the use of the S-LCA methodology and selected indicators for the current study enabled the following results:

- Identification of raw materials sectors in EU-28 with the highest social risks among those industries in scope of the European policy on raw materials.
- Investigation of the supply chains of raw materials industries in EU-28 and quantification of social risks associated directly (i.e. in the sector itself) and indirectly (i.e. in the upstream chain) to the industrial branches analysed.
- Geographic localization of the main social hotspots of raw materials sectors in EU-28.
- Comparison of the social performance of raw materials sectors between EU-28 and extra-EU countries previously defined in the study.

Results are further discussed in the following sections in terms of (1) the suitability (potentials and limitations) of S-LCA methodology and tools to support a sustainable raw materials supply for the EU and (2) the interpretation of the outcomes of the study, i.e. quantified social risks, in the EU and extra-EU context.

4. Discussion

4.1. Strength and weakness of the study

The S-LCA methodology and the PSILCA database allowed for the assessment of a wide range of social risks in selected raw materials sectors. It was possible to identify the most contributing processes and social hotspots, leading to a quantification and visualization of information both for sectoral assessment and comparison analyses. Therefore, the potential of a life-cycle-based approach to capture social risks in raw materials supply chains has clearly emerged. Indeed, the results displayed that social risks in the EU-28 selected industries are spread worldwide and are often associated with sectors which are input to raw materials production and manufacturing. Thus, the effort towards a more sustainable raw materials industry can benefit from the application of tools and methods which are capable to analyse the geographic distribution and most significant sources of social risks in upstream chains. Furthermore, the present study gave insight into the social performance of EU and extra-EU regions for the sectors under study by using existing social data and indicators in PSILCA. The research showed how selected and already available social indicators used in S-LCA can be further aggregated to propose social categories. These categories may become new quantification metrics to monitor raw materials sustainability on a policy level. For instance, the RMS currently contains indicators which are not life cycle based and have a limited focus on social issues.

Social information in PSILCA is clearly the basis of the presented results. The assessment of data quality with the use of a pedigree matrix (Eisfeldt 2017) and documentation of data sources emerged as a priority, hence efforts were made towards improving the transparency and traceability of the research. Some impact categories required approximations and adaptations. Specifically, data for “Child labour” and for some indicators of “Freedom of association and collective bargaining” and “Contribution to economic development” are not sector-specific. This implies that differences among national industries regarding social risks measured by non-sector specific indicators may be due to either different worker hours or monetary inputs to the sector, and not due to a variation in the risk level. The current inability of such indicators to capture the risk variability among national economy sectors should be held in regard when interpreting results. Furthermore, one indicator for the “Corruption” category is based on a data source with low reliability. Table 5 displays the data quality for the results of the study, evaluated according to five criteria: Reliability of the source(s) (R), Completeness conformance (C), Temporal conformance (T), Geographical conformance (G), and Further technical conformance (F). The score given to the results ranges from 1 (best quality) to 5 (worst quality) for each criterion. The table provides information on data quality as an average of the six sectors analysed in the present study, although data quality assessment is available for every sector in PSILCA. The categories “Fair salary”, “Respect of Indigenous rights”, “Contribution to economic development”, and “Migration” present on average a good data quality.

As for weaknesses deriving from the methodology applied to this analysis, sectoral and regional aggregation of EU-28 countries could be the main source of uncertainty together with the use of a cut-off for the calculations. Furthermore, uncertainties related to statistical data from different sources have been remarked in existing studies (ILO 2017) with reference to possible limitations linked to data quality and gaps. In conclusion, a first level of uncertainty derives directly from the multi-regional input/output model which is the backbone of the PSILCA database (Lenzen et al. 2010), for instance regarding the harmonization of different data sources.

4.2. Interpretation and context of results

Many risks in EU-28 raw materials industries originate in non-EU countries, specifically India and China. The major sources of risks derive from sectors which are an input to resource extraction and manufacturing, such as the construction and metal manufacturing industries. Given the economic globalization of production, markets and technologies, developing countries often provide the EU with equipment and parts needed for raw materials extraction and processing activities. Specifically, “Mining and quarrying”, which displays the worst social performance among the selected industries in EU-28, sees the highest share of risks occurring in the supply chain rather than in the sector itself.

A worldwide high risk of corruption in raw materials industries emerged from the study. Together, the extractive and construction sectors account for 35% of all foreign bribery cases, resulting those that have been sanctioned the most according to the OECD Foreign Bribery Report (OECD 2014). In this framework, it is interesting to note that construction processes in the present research often have large contributions to social risks in supply chains of European raw materials industries. Overall, the study illustrated that the supply chain has a large impact on the results for EU-28. However, in the case of some sectors, significant direct social risks can be identified as well, for example in the category "Health and Safety". Indeed, sectors which are based on manual operations and self-employment, such as "Forestry and Logging", may lack sufficient safety measures to prevent fatal and non-fatal accidents (EC – European Commission 2018). As for more mechanized sectors in terms of equipment and machineries, such as "Mining and quarrying", direct impacts are notably reduced (less than 5% of overall risks) and the largest share is further caused by upstream processes. Together with "Corruption" and "Health and Safety", two other social categories emerged as important from the research for both EU and extra-EU countries: "Fair salary" and "Freedom of association and collective bargaining". In the case of "Fair salary", the risk of workers not receiving a reasonable and adequate wage is influenced by both the cost of living in the country and the presence of regulations on minimum wage. Possible discrepancies in regulatory quality of different countries may exacerbate the social risk of an unfair salary. In addition, inequalities in the distribution of wealth among diverse society groups and working time may potentially weigh on this social category (Neugebauer et al. 2017). Developing countries may more often incur income inequalities, which increases the risks of an unfair salary in the supply chains of European raw materials industries. Furthermore, it may be useful to highlight that "Fair salary" is the impact category with the best data quality.

The social theme "Freedom of association and collective bargaining" reflects workers' rights issues which are often not sector-specific. Indeed, workers´ rights may be affected by the general political situation and respect of human rights in place in a country. Therefore, an investigation of the country, and often of the local, social, and socio-economic context, appears important to interpret social risks and identify cause-effect relationships between risks and "background" situations, i.e. those situations which can exacerbate risks and enhance opportunities (Di Noi and Ciroth 2018). On a broader level, as part of the EU methodology to assess resource criticality (Blengini et al. 2017), World Governance Indicators (WGI) are used in the form of an aggregated average as a weighting factor for the supply risk associated to a raw materials producer country. Governance and human rights issues reflected by WGIs may create or influence resource supply risks. Therefore, for a better interpretation of results of the research, socio-economic and governance situations in extra-EU countries are investigated by analysing WGIs (World Bank 2016) and the Human Development Index (UNDP 2016), see

Table 6. The aim is to detect if and how social risks may be connected to these situations. A close relation between social risks and governance and human development conditions is outlined for country A and F. For these two countries, the highest level of socio-economic and political development corresponds to the lowest risks for most social categories in all raw materials sectors considered. As for the other countries, it is not possible to identify a clear correspondence and cause-effect relationship between specific country conditions and social issues.

5. Conclusions

The study investigated whether and how the Social Life Cycle Assessment (S-LCA) methodology can support responsible sourcing of raw materials in Europe. The potential of social indicators already available in an S-LCA database is tested for the development of new metrics to monitor social risks in raw materials industries at EU policy level. 9 social themes and, consequently, impact categories were identified in the PSILCA database and used to analyse social risks and hotspots in selected raw materials sectors in EU-28 and non-EU countries, considering the supply chain. “Corruption”, “Fair salary”, “Health and safety”, and “Freedom of association and collective bargaining” emerged as the most significant social risks both in EU and extra-EU. Furthermore, an investigation of the most contributing processes to social impact categories for EU-28 led to the identification of important risks originating in the supply chain and in extra-EU areas. Especially upstream processes have a major share in the overall social risks in the EU sector “Mining quarrying”, which also displays the worst social performance among the analysed EU-28 industries. Considering the resulting widespread distribution of risks at geographic and supply chain levels, the S-LCA methodology confirmed the high potential of a life cycle perspective to detect burdens shifting and trade-offs. However, only a limited view on the sectoral social performance could be obtained from the research because a number of social indicators, such as child labour and illiteracy rate, only provide information on a country level. Furthermore, regional differences within countries are not captured by the existing indicators in the RMS 2018 nor could they be detected by the present study, as S-LCA databases only contain social data per country-sector. Indeed, further efforts should be made to evaluate social risks at subnational levels in view of regional variability. Therefore, it can be concluded that the S-LCA methodology and indicators appear appropriate to perform an initial social sustainability screening, by enabling the identification of hotspots in raw materials supply chains and the prioritization of areas of action in EU policies. For instance, the approach presented in the study may support resource criticality assessment and the evaluation of social performance of EU trade partners. Furthermore, due diligence in raw materials supply chains and fairness in public procurement may benefit from the application of the methodological framework discussed in the present article. However, the outcomes obtained with such methodological framework should be further investigated at a more detailed level, for instance considering the subnational context and weaknesses of the study. Limitations connected with uncertainties of results and data quality should always be reported in order to preserve transparency and quality of the outcomes.

Finally, methodological developments in S-LCA could increase the suitability of a life-cycle-based approach and related indicators already available in S-LCA databases to become monitoring models for social sustainability of EU raw materials industries. Future outlooks may involve discussions on activity variable, aggregation of social indicators in social impact categories, and combination of country- and sector-specific social data in databases. Further research may also address how to assess social risks for secondary raw materials or in other life cycle stages beyond production, such as use and end of life. Apart from negative social impacts, it would be interesting to address positive contributions, i.e. opportunities, to social issues deriving from raw materials sectors. However, this topic is still a matter of debate as there are different and unclear positions on how positive social impacts should be considered regarding the methodological and conceptual framework (Di Cesare et al.2018).

In summary, the research analysed potentials and limitations of S-LCA indicators and methodologies to contribute to the challenges of social sustainability in the EU raw materials supply, as a major concern of European policies in the last years, for instance in relation to the sourcing of materials from conflict-affected areas. Further methodological developments in the S-LCA field are necessary to make the approach proposed in the paper fully adequate to support EU policies on raw materials.

Acknowledgements The authors would like to thank Tim Lohse for his suggestions that helped improving the manuscript.

Conflict of interest The authors declare that they have no conflict of interest.

6. References

Best A, Giljum S, Simmons C, Blobel D, Lewis K, Hammer M, Cavalieri S, Lutter S, and Maguire C (2008) Potential of the Ecological Footprint for monitoring environmental impacts from natural resource use: Analysis of the potential of the Ecological Footprint and related assessment tools for use in the EU's Thematic Strategy on the Sustainable Use of Natural Resources. Report to the European Commission, DG Environment. http://ecologic.eu/sites/files/download/projekte/950-999/968/968_footprint_study.pdf. Accessed 16 May 2017

Blengini GA, Blagoeva D, Dewulf J, Torres de Matos C, Nita V, Vidal-Legaz B, Latunussa C, Kayam Y, Talens Peirò L, Baranzelli CEL, Manfredi S, Mancini L, Nuss P, Marmier A, Alves-Dias P, Pavel C, Tzimas E, Mathieux F, Pennington D, Ciupagea C (2017) Assessment of the Methodology for Establishing the EU List of Critical Raw Materials. DOI 10.2760/130462 (print) 10.2760/73303 (online), ISBN 978-92-79-69611-4 (print), 978-92-79-69612-1 (pdf)

Di Cesare S, Silveri F, Sala S, Petti L (2018) Positive impacts in social life cycle assessment: state of the art and the way forward. Int J Life Cycle Assess 23:406–421 doi:10.1007/s11367-016-1169-7

Di Noi C, Ciroth A (2018) Environmental and Social Pressures in Mining. Results from a Sustainability Hotspots Screening. Resources 7, 80. https://doi.org/10.3390/resources7040080

EC—European Commission (2010) Critical raw materials for the EU. Report of the Ad-Hoc Working Group on Defining Critical Raw Materials, Brussels

EC – European Commission (2015) A Global Partnership for Poverty Eradication and Sustainable Development after 2015. COM(2015) 44

EC – European Commission (2016) Next steps for a sustainable European future. European action for sustainability. COM(2016) 739

EC – European Commission (2016) Raw Materials Scoreboard. doi:10.2873/686373 ISBN:978-92-79-61700-3

EC – European Commission (2017) Communication from the Commission \u2014 Guidelines on non-financial reporting (methodology for reporting non-financial information (2017/C 215/01)

EC – European Commission (2017) Methodology for establishing the EU list of Critical Raw Materials. Guidelines. ISBN 978-92-79-68051-9

EC – European Commission (2018) European pillar on social rights. Publications Office of the European Union. ISBN 978-92-79-74092-3

EC – European Commission (2018) Raw Materials Scoreboard. doi:10.2873/08258 ISBN 978-92-79-89745-0

EC – European Commission (2018) Report on Critical Raw Materials and the Circular Economy. SWD(2018) 36

Eisfeldt F (2017) PSILCA – A Product Social Impact Life Cycle Assessment database. Database version 2.1, Documentation, version 3. http://www.openlca.org/wpcontent/uploads/2017/12/PSILCA_documentation _update PSILCA_v2_final.pdf. Accessed 12 February 2018

EU – European Union (2017) Regulation (EU) 2017/821 of the European Parliament and of the Council of 17 May 2017, laying down supply chain due diligence obligations for union importers of tin, tantalum and tungsten, their ores, and gold originating from conflict-affected and high-risk areas

Eurostat (2017) Annual enterprise statistics for special aggregates of activities (NACE Rev. 2). http://appsso.eurostat.ec.eur opa.eu/nui/submitViewTableAction.do. Accessed 26 April 2017

Frost & Sullivan (2014) Social Innovation Whitepaper. http://www.hitachi.eu/sites/default/files/fields/document/sib/whitepapers/whitepaper_0011.pdf. Accessed 9 May 2019

Graedel TE, Barr R, Chandler C, Chase T, Choi J, Christoffersen L, Friedlander E, Henly C, Jun C, Nassar NT, Schechner D, Warren S, Yang M, Zhu C (2012) Methodology of metal criticality determination. Environ Sci Technol 46:1063–1070

Helbig C, Wietschel L, Thorenz A, Tuma A (2016) How to evaluate raw material vulnerability-an overview. Resour Policy 48 (2016) 13-24

ILO (2017) Quick guide on sources and uses of labour statistics. Geneva, Switzerland. ISBN:978-92-2-130119-6

Klinglmair M, Sala S, Brandao M (2014) Assessing resource depletion in LCA: a review of methods and methodological issues. Int J Life Cycle Assess 19:580–592

Lenzen M, Kanemoto K, Moran D, Geschke A (2012) Mapping the structure of the world economy. Environ. Sci. Technol., 46(15) pp. 8374-8381. doi: 10.1021/es300171x

Lenzen M, Moran D, Kanemoto K, Geschke A (2013) Building Eora: A Global Multiregional Input-Output Database at High Country and Sector Resolution. Econ. Syst. Res., 25:1, 20-49, DOI:10.1080/09535314.2013.769938

Lenzen M, Wood R, and Wiedmann T (2010) Uncertainty analysis for multi-region input–output models – a case study of the Uk's Carbon Footprint. Econ. Syst. Res., vol. 22, no. 1, pp. 43–63

Mancini L, Benini L, Sala S (2018) Characterization of raw materials based on supply risk indicators for Europe. Int J Life Cycle Assess 23:726. doi:10.1007/s11367-016-1137-2

Mancini L, Sala S, Pennington D (2013) From scarcity to security: a rationale for resources in LCA. Conference Paper

Mancini L, Sala S, Recchioni M, Benini L, Goralczyk M, Pennington D (2015) Potential of life cycle assessment for supporting the management of critical raw materials. Int J Life Cycle Assess 20:100–116

Mancini L, Vidal Legaz B, Vizzarri M, Wittmer D, Grassi G, Pennington D (2018) Mapping the role of Raw Materials in Sustainable Development Goals. A preliminary analysis of links, monitoring indicators and related policy initiatives. EUR 29595 EN, Publications Office of the European Union, Luxembourg, ISBN: 978-92-79-98482-2, doi:10.2760/933605, JRC112892

Neugebauer S, Emara Y, Hellerström C, Finkbeiner M (2017). Calculation of Fair wage potentials along products' life cycle – Introduction of a new midpoint impact category for social life cycle assessment. J Clean Prod, Vol. 143 (1), pp. 1221-1232. *dx.doi.org/10.1016/j.jclepro.2016.11.172*

OECD (2014) OECD Foreign Bribery Report: An Analysis of the Crime of Bribery of Foreign Public Officials. OECD Publishing. http://dx.doi.org/10.1787/9789264226616-en. Accessed 8 May 2019

OECD (2016) Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-affected and High-Risk Areas. Third edition, OECD Publishing, Paris. http://www.oecd.org/daf/inv/mne/OECD-Due-Diligence-Guidance-Minerals-Edition3.pdf. Accessed 8 May 2018

Reichl C, Schatz M, Zsak G. (Federal Ministry of Science, Research and Economy) (2016) World Mining Data. Volume 31, Minerals Production. https://www.en.bmwfw.gv.at/Energy/Documents/WMD2016.pdf. Accessed 2 May 2017

Sonnemann G, Gemechu ED, Adibi N, De Bruille V, Bulle C (2015) From a critical review to a conceptual framework for integrating the criticality of resources into life cycle sustainability assessment. J Clean Prod 94:20–34

UNDP (United Nations Development Programme) (2016) Human Development Index (HDI). http://hdr.undp.org/en/content/human-development-index-hdi. Accessed 5 April 2018

UNEP/SETAC Life Cycle Initiative (2009) Guidelines for social life cycle assessment of products. Authors: Andrews E S, Barthel L-P, Beck T, Benoit C, Ciroth A, Cucuzella C, Gensch C-O, Hérbert J, Lesage P, Manhart A, Mazeau P, Mazijn B, Methot A-L, Moberg A, Norris G, Parent J, Prakash S, Reveret J-P, Spillemaeckers S, Ugaya C M L, Valdivia S, Weidema B. www.unep.fr/scp/publications/details.asp?id=DTI/ 1164/PA. Accessed 5 April 2018

UNEP/SETAC Life Cycle Initiative (2013) The methodological sheets for subcategories in social life cycle assessment (S-LCA) Authors: Aulisio D, Azuero L, Benoit C, Ciroth A, Franze J, Mazijn B, Traverso M, Valdivia S, Vickery-Niederman G, https://www.lifecycleinitiative.org/wp-content/uploads/2013/11/S-LCA_methodological_sheets_11.11.13.pdf . Accessed 7 May 2019

World Bank (2016) Worldwide Governance Indicators. http://info.worldbank.org/governan ce/wgi/#doc-intro. Accessed 5 April 2018

7. Tables

Table 1 *Example of regional and sectoral aggregation in EU raw materials processes in PSILCA: some inputs of the process "EU Mining and Quarrying"*

EU Mining and quarrying			
Flow	**Category**	**Amount**	**Unit**
Metal ores - SK	PSILCA - Products/Slovakia/Commodities	**0.5***Perc_SK	USD
Other mining and quarrying products - SK	PSILCA - Products/Slovakia/Commodities	**0.5***Perc_SK	USD
Other mining and quarrying products - SI	PSILCA - Products/Slovenia/Commodities	**0.5***Perc_SI	USD
Metal ores - SI	PSILCA - Products/Slovenia/Commodities	**0.5***Perc_SI	USD
Metal ores - SE	PSILCA - Products/Sweden/Commodities	**0.5***Perc_SE	USD
Other mining and quarrying products - SE	PSILCA - Products/Sweden/Commodities	**0.5***Perc_SE	USD
Iron ore mining - ES	PSILCA - Products/Spain/Commodities	**0.2***Perc_ES	USD
Non-ferrous metal ores - ES	PSILCA - Products/Spain/Commodities	**0.2***Perc_ES	USD
Non-metallic non-energetic ores - ES	PSILCA - Products/Spain/Commodities	**0.2***Perc_ES	USD
Mining of metal ores - ES	PSILCA - Products/Spain/Industries	**0.2***Perc_ES	USD
Other mining and quarrying - ES	PSILCA - Products/Spain/Industries	**0.2***Perc_ES	USD
….			

Table 2 *Criteria for indicator and subcategory selection*

Relevance criteria	1. **Relevance for the raw material sectors**
	2. Policy relevance and acceptability
Impact category criteria	3. Link between the topic of the impact category and the indicators
	4. Impact category comprehensiveness
Data Quality criteria	5. Basis for indicator risk assessment
	6. Reliability of the data sources
	7. Appropriate geographic and technical resolution of the indicator data

Table 3 *Selected impact categories with respective indicators, their units of measurement, main data sources, and risk assessment scheme (nr: no risk; vlr: very low risk; lr: low risk; mr: medium risk; hr: high risk; vhr: very high risk)*

Stakeholder	Impact category	Indicator	Unit of measurement	Main data sources	Risk assessment
Workers	Health and Safety	Rate of non-fatal accidents at workplace	Cases per 100,000 employees and year	ILOstat 2014	0≤y<750 → vlr; 750≤y<1500 → lr; 1500≤y<2250 → mr; 2250≤y<3000 → hr; 3000≤y → vhr
		Rate of fatal accidents at workplace	Cases per 100,000 employees and year		0≤y<7.5 → vlr ;7.5≤y<15 → lr; 15≤y<25 → mr; 25≤y<40 → hr; 40≤y → vhr
		DALYs due to indoor and outdoor air and water pollution	DALYs per 1,000 inhabitants in the country	WHO 2009	0=y → nr; 0<y<5 → vlr; 5<y<15 → lr; 15<y<30 → mr; 30<y<50 → hr; 50≤y →vhr
		Presence of sufficient safety measures	OSHA cases per 100,000 employees in the sector	United States Department of Labor (USDOL) 2014: Occupational Safety and Health Administration (OSHA)	0<y<100 → vlr; 100≤y<300 → lr; 300≤y<600 → mr; 600≤y<1000 → hr; 1000≤y → vhr
		Workers affected by natural disasters	Affected persons as % of whole population between 2012 and 2014	EM_DAT – The International Disaster Database 2015	0≤y<1 → vlr; 1≤y<3 → lr; 3≤y<5 → mr; 5≤y<10 → hr; 10≤y → vhr
	Freedom of association and collective bargaining	Trade union density	% of employees organised in trade unions	ILOstat 2014	20≥y →vhr; 20<y≤40 → hr; 40<y≤60 → mr; 60<y≤80→ lr; 80>y → vlr
		Right of Association	Score of ordinal scale 0-3 scale	University of Amsterdam: ICTWSS: Database on Institutional Characteristics of Trade Unions, Wage Setting, State Intervention and Social Pacts in 51 countries between 1960 and 2013	0=No; 1=Yes, with major restrictions; 2=Yes, with minor restrictions; 3=Yes
		Right of Collective bargaining	Score of ordinal scale 0-3 scale		
		Right to strike	Score of ordinal scale 0-3 scale		
	Child labour	Child labour, total	% of all children ages 7-14	World Bank 2014	0=y → nr; 0<y<2.5 → vlr; 2.5<y<5 → lr ; 5<y<10 → mr; 10<y<20 → hr; 20≤y → vhr
	Fair salary	Living wage, per month	USD	WageIndicator 2014	y<100 → vlr; 100≤y<200 → lr; 200≤y500 → mr; 500≤y1000 → hr; 1000≤y → vhr
		Minimum wage, per month	USD		1000≤y → vlr; 500≤y<1000 → lr; 300≤y<500 → mr; 200≤y<300 → hr; y<200 → vhr; if Living wage (LW) is available: x=LW/MW; x<0.5 → vlr; y>300 AND 0.5≤x<0.9 → lr; (y≤300 AND 0.5≤x≤0.9) OR (y>300 AND 0.9≤x<0.3) → mr; (y≤300 AND 0.9≤x≤1.3) OR (y>300 AND 1.3≤x<1.8) → hr; (y≤300 AND 1.3≤x≤1.8) OR (x≥1.8) → vhr;
		Sector average wage, per month	USD	ILOstat 2014	0<y<1 → vhr; 1≤y<1.5 → hr; 1.5≤y<2 → mr; 2≤y<2.5 → lr; 2.5≤y → vlr
	Working time	Hours of work per employee, per week	H		40≤y<48 → lr; 30≤y<40 OR 48≤y<55 → mr; 20≤y<30 OR 55≤y<60 → hr; 60≤y vhr

Local communities	Respect of indigenous rights	Presence of indigenous population	Y/N	Wikipedia 2015	No=nr; Yes=mr
		Human right issues faced by indigenous people	Score	ILO 1989: Indigenous Peoples Convention; UN Declaration of indigenous rights; United Nations Department of Economic and Social Affairs (UN-DESA)	$y=5 \rightarrow$ vlr; $y=4 \rightarrow$ lr; $y=3 \rightarrow$ mr; $y=2 \rightarrow$ hr; $y+1$ OR $0 \rightarrow$ vhr
	Migration	International migrant workers in the sector	% (employed international migrant population related to total employed population)	ILO 2010	Difference x to migrant stock, % $y=0 \rightarrow$ nr $0<y\leq 2.5$ AND $x\leq \lvert 5 \rvert \rightarrow$ vlr; $2.5<y\leq 5$ AND $x\leq \lvert 5 \rvert \rightarrow$ lr; $5<y\leq 10$ AND ($x\leq \lvert 5 \rvert$ OR $\lvert 5 \rvert <y\leq \lvert 10 \rvert$) $\rightarrow$ mr; $10<y\leq 20$ AND ($x\leq \lvert 5 \rvert$ OR $\lvert 10 \rvert <y\leq \lvert 15 \rvert$) $\rightarrow$ hr; $y\geq 20$ AND $x\leq \lvert 15 \rvert \rightarrow$ vhr
		International Migrant Stock	% (of total population)	United Nations Department of Economic and Social Affairs	$0=y \rightarrow$ nr; $0<y<2.5 \rightarrow$ vlr; $2.5\leq y<5 \rightarrow$ lr; $5\leq y<10 \rightarrow$ mr; $10\leq y<20 \rightarrow$ hr; $20\leq y \rightarrow$ vhr
		Net migration rate	% (= per 1,000 persons)	World Factbook 2014	$0=y \rightarrow$ nr; $0<y< \lvert 2.5 \rvert \rightarrow$ vlr; $2.5 \lvert \leq y< \lvert 5 \rvert \rightarrow$ lr; $\lvert 5 \rvert \leq y< \lvert 10 \rvert \rightarrow$ mr; $\lvert 10 \rvert \leq y< \lvert 15 \rvert \rightarrow$ hr; $\lvert 15 \rvert \leq y \rightarrow$ vhr
Value Chain actors	Corruption	Public sector corruption	Score (Corruption Perception Index score of the country)	Transparency International 2012	$100\geq y\geq 85 \rightarrow$ vlr; $84\geq y\geq 75 \rightarrow$ lr; $74\geq y\geq 65 \rightarrow$ mr; $64\geq y\geq 55 \rightarrow$hr; $55\geq y \rightarrow$ vhr
		Active involvement of enterprises in corruption and bribery	% of sector- related cases out of all registered foreign bribery cases	OECD 2014	$0<y\leq 3 \rightarrow$ vlr; $3<y\leq 7 \rightarrow$ lr; $7<y\leq 11 \rightarrow$ mr; $11<y\leq 14 \rightarrow$ hr; $14<y \rightarrow$ vhr
Society	Contribution to economic development	Contribution of the sector to economic development	% of GDP	UNSTAT 2015	$0\leq y<1 \rightarrow$ no opportunity; $1\leq y\leq 10 \rightarrow$ low opportunity; $10<y\leq 25 \rightarrow$ medium opportunity; $25<y \rightarrow$ high opportunity
		Public expenditure on education	% of GDP	World Bank 2014	$0\leq y<2.5 \rightarrow$ vhr; $2.5\leq y<5 \rightarrow$ hr; $5\leq y<7.5 \rightarrow$ mr; $7.5\leq y<10 \rightarrow$ lr; $10\leq y \rightarrow$ vlr
		Adult illiteracy rate (15+ years), male	% of male population	UNESCO 2014	$0\leq y<1 \rightarrow$ vlr; $1\leq y<4 \rightarrow$ lr; $4\leq y<8 \rightarrow$ mr; $8\leq y<15 \rightarrow$ hr; $15\leq y \rightarrow$ vhr
		Adult illiteracy rate (15+ years), female	% of female population		
		Adult illiteracy rate (15+ years), total	% of total population		
		Youth illiteracy rate, male	% of male population, 15-24		
		Youth illiteracy rate, female	% of female population, 15-24		
		Youth illiteracy rate, total	% of total population, 15-24		

***Table 4**: Top process contributions to “Fair salary” in the “Mining and quarrying” sector in EU-28 (FS=Fair Salary)*

Name	Category	Impact result	Unit
Fair salary - Mining and quarrying, EU 28		9.37109	FS med risk hours
Construction - IN	India / Industries	0.49113	FS med risk hours
Construction - IN	India / Commodities	0.47825	FS med risk hours
Non-ferrous basic metals - IN	India / Industries	0.25078	FS med risk hours
Other service activities - IN	India / Commodities	0.23176	FS med risk hours
Non-ferrous basic metals - IN	India / Commodities	0.22159	FS med risk hours
Manufacturing - IN	India / Industries	0.19093	FS med risk hours
Other service activities - IN	India / Industries	0.18793	FS med risk hours
Trade - IN	India / Commodities	0.17839	FS med risk hours
Health - CN	China / Commodities	0.1783	FS med risk hours
Manufacturing - IN	India / Commodities	0.15911	FS med risk hours

***Table 5**: Data quality assessment for the results of the study. Legend: Reliability of the source(s) (R), Completeness conformance (C), Temporal conformance (T), Geographical conformance (G), and Further technical conformance (F)*

Country	Impact subcategory	Average data quality among sectors				
		R	C	T	G	F
Australia	Child labour, total	2	4	5	4	5
Australia	Contribution to economic development	2	2	2	1	3
Australia	Corruption	4	3	1	1	3
Australia	Fair salary	1	2	1	1	1
Australia	Freedom of association and collective bargaining	2	2	4	1	5
Australia	Health and Safety (Workers)	1	2	1	3	2
Australia	Migration	1	2	2	1	2
Australia	Respect of indigenous rights	2	3	1	1	n.a.
Australia	Working time	2	2	2	1	2
Brazil	Child labour, total	2	4	4	2	5
Brazil	Contribution to economic development	2	2	2	1	3
Brazil	Corruption	4	3	1	1	2
Brazil	Fair salary	2	3	1	1	1
Brazil	Freedom of association and collective bargaining	2	2	4	1	5
Brazil	Health and Safety (Workers)	1	2	2	3	2
Brazil	Migration	2	3	3	2	4
Brazil	Respect of indigenous rights	2	2	1	1	n.a.
Brazil	Working time	2	2	3	1	2
China	Child labour, total	2	4	5	4	5
China	Contribution to economic development	4	4	3	3	3
China	Corruption	4	3	1	1	4
China	Fair salary	2	3	1	1	1
China	Freedom of association and collective bargaining	2	3	3	1	4
China	Health and Safety (Workers)	2	2	2	3	3
China	Migration	3	3	3	3	4
China	Respect of indigenous rights	2	2	1	1	n.a.
China	Working time	2	2	5	1	2
EU	Child labour, total	2	4	5	3	5
EU	Contribution to economic development	2	2	3	1	3
EU	Corruption	4	3	1	1	2
EU	Fair salary	1	2	1	1	1
EU	Freedom of association and collective bargaining	2	2	4	1	5
EU	Health and Safety (Workers)	1	2	2	3	2

EU	Migration	2	2	4	1	2
EU	Respect of indigenous rights	2	3	1	1	n.a.
EU	Working time	2	2	1	1	2
Russia	Child labour, total	2	4	4	4	5
Russia	Contribution to economic development	2	2	3	1	3
Russia	Corruption	4	3	1	1	2
Russia	Fair salary	2	3	1	1	1
Russia	Freedom of association and collective bargaining	2	2	4	1	5
Russia	Health and Safety (Workers)	1	2	1	4	2
Russia	Migration	1	2	2	1	4
Russia	Respect of indigenous rights	2	3	1	1	n.a.
Russia	Working time	2	2	4	1	2
South Africa	Child labour, total	2	4	5	1	5
South Africa	Contribution to economic development	2	2	2	1	3
South Africa	Corruption	4	3	1	1	3
South Africa	Fair salary	2	3	1	1	1
South Africa	Freedom of association and collective bargaining	2	2	5	1	5
South Africa	Health and Safety (Workers)	2	3	4	2	3
South Africa	Migration	2	2	3	1	3
South Africa	Respect of indigenous rights	1	2	1	1	n.a.
South Africa	Working time	2	3	4	1	3
United States	Child labour, total	2	4	5	4	5
United States	Contribution to economic development	1	2	3	1	3
United States	Corruption	3	3	1	1	3
United States	Fair salary	1	1	1	1	1
United States	Freedom of association and collective bargaining	2	2	4	1	5
United States	Health and Safety (Workers)	1	2	1	4	2
United States	Migration	1	2	2	1	4
United States	Respect of indigenous rights	2	3	1	1	n.a.
United States	Working time	2	3	3	1	3

***Table 6**: Human Development Index and World Governance Indicators referred to countries A to F*

	Human Development Index*	World Governance Indicators (2016)**					
		Voice and Accountability	Political Stability and absence of violence/terrorism	Government Effectiveness	Regulatory Quality	Rule of Law	Control of Corruption
A	0.939	1.3	0.96	1.58	1.9	1.75	1.77
B	0.754	0.47	-0.45	-0.18	-0.21	-0.08	-0.44
C	0.738	-1.62	-0.52	0.36	-0.26	-0.22	-0.25
D	0.804	-1.21	-0.89	-0.22	-0.42	-0.80	-0.86
E	0.666	0.64	-0.13	0.27	0.21	0.07	0.05
F	0.920	1.1	0.35	1.48	1.50	1.67	1.33

* Human Development Index combines three dimensions (A long and healthy life; Education index; A decent standard of living) and ranges from 0 (lowest) to 1 (highest) development level
**Estimate of governance ranges from approximately -2.5 (weak) to 2.5 (strong) governance performance

8. Figure and Table captions

Table 1 Example of regional and sectoral aggregation in EU raw materials processes in PSILCA: some inputs of the process “EU Mining and Quarrying”

Table 2 Criteria for indicator and subcategory selection

Table 3 Selected impact categories with respective indicators, their units of measurement, main data sources, and risk assessment scheme (nr: no risk; vlr: very low risk; lr: low risk; mr: medium risk; hr: high risk; vhr: very high risk)

Table 4: Top process contributions to “Fair salary” in the “Mining and quarrying” sector in EU-28 (FS=Fair Salary)

Table 5: Data quality assessment for the results of the study. Legend: Reliability of the source(s) (R), Completeness conformance (C), Temporal conformance (T), Geographical conformance (G), and Further technical conformance (F)

Table 6: Human Development Index and World Governance Indicators referred to countries A to F

Figure 1 Social risks in different raw materials industries in EU-28

Figure 2 Contributions of three biotic raw materials sectors to total social risks of biotic raw materials production in EU-28

Figure 3 Relative direct (from mining industry in EU-28) and indirect (from upstream chain) contributions to final social risks of EU-28 “Mining and quarrying” sector

Figure 4 Relative direct (from forestry and logging industry in EU-28) and indirect (from upstream chain) contributions to final social risks of EU-28 “Forestry and logging” sector

Figure 5 Main social hotspots (locations) regarding the risk of a limited freedom of association and collective bargaining of “Forestry and Logging” in EU-28 (screenshot from openLCA). Top 3 contributing locations: China, Poland, Germany

Figure 6 Main social hotspots (locations) for the category “Fair salary” of “Manufacture of basic metals” in EU-28 (screenshot from openLCA). Top 3 contributing locations: India, Germany, China

Figure 7 Social risks of selected raw materials production sectors in EU-28 and extra-EU countries

Figure 8 Social risks regarding “Manufacture of basic metals” sector in all selected countries and in EU-28 region

Figure 9 Social risks regarding “Mining and quarrying” sector in all selected countries and in EU-28 region

9. Figures

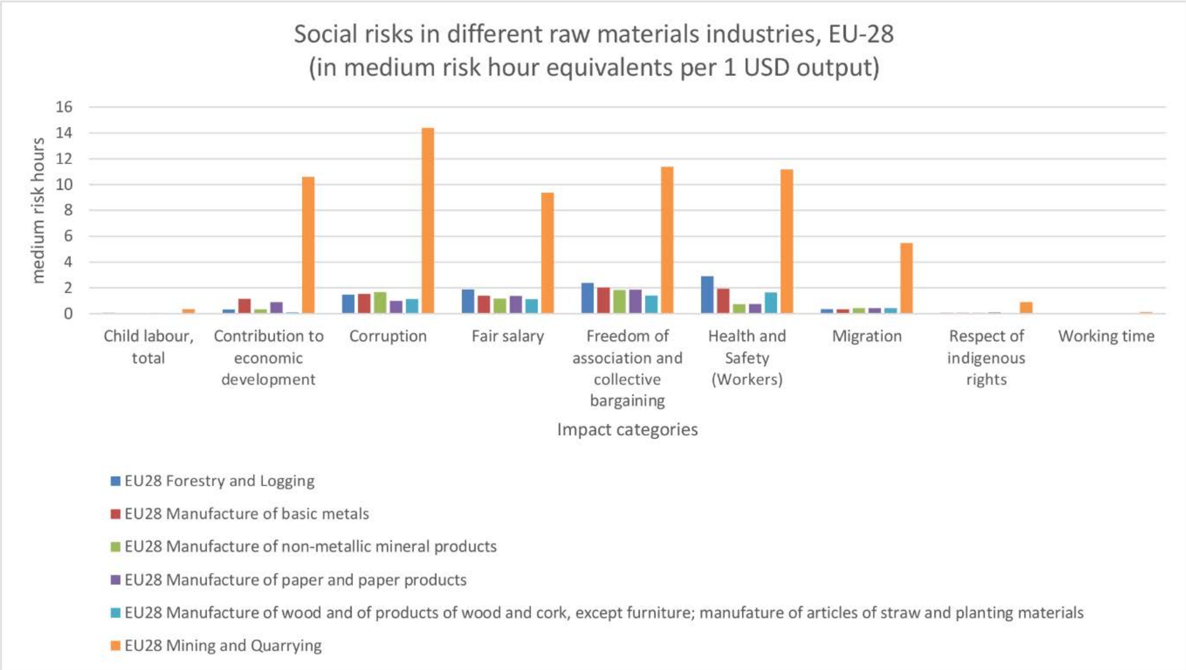

Figure 1 *Social risks in different raw materials industries in EU-28*

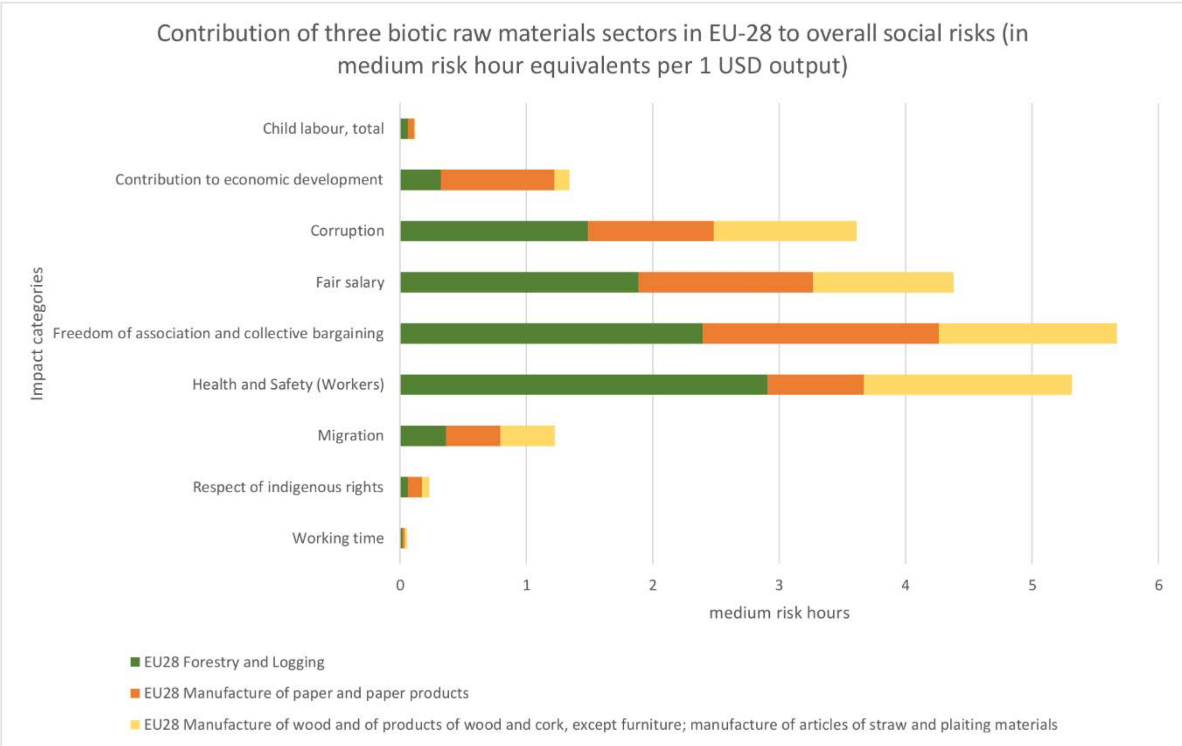

Figure 2 *Contributions of three biotic raw materials sectors to total social risks of biotic raw materials production in EU-28*

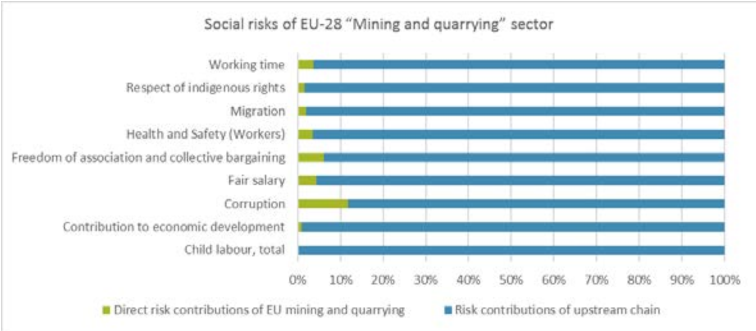

Figure 3 *Relative direct (from mining industry in EU-28) and indirect (from upstream chain) contributions to final social risks of EU-28 "Mining and quarrying" sector*

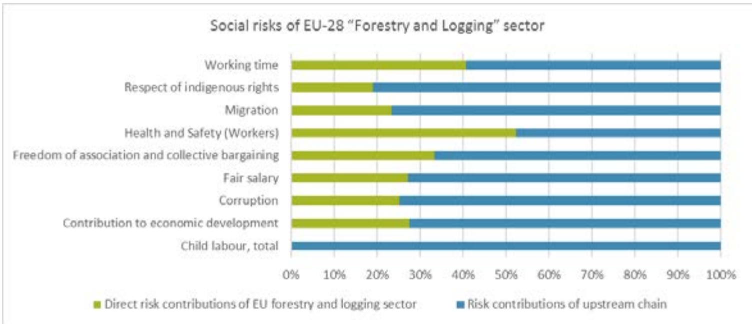

Figure 4 *Relative direct (from forestry and logging industry in EU-28) and indirect (from upstream chain) contributions to final social risks of EU-28 "Forestry and logging" sector*

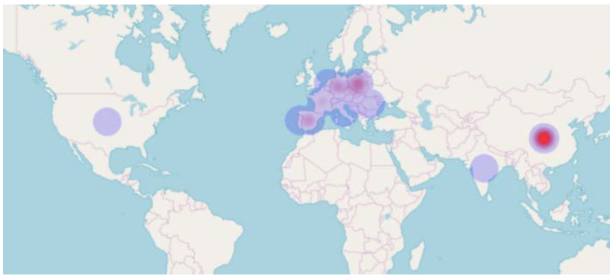

Figure 5 *Main social hotspots (locations) regarding the risk of a limited freedom of association and collective bargaining of "Forestry and Logging" in EU-28 (screenshot from openLCA). Top 3 contributing locations: China, Poland, Germany*

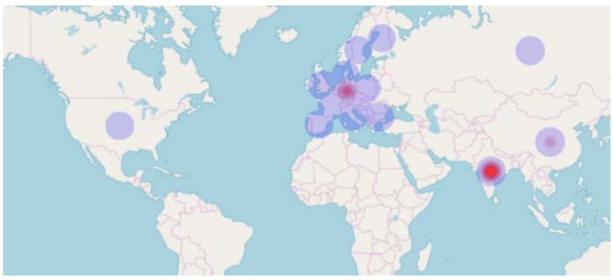

Figure 6 *Main social hotspots (locations) for the category "Fair salary" of "Manufacture of basic metals" in EU-28 (screenshot from openLCA). Top 3 contributing locations: India, Germany, China*

Sector	Child labour, total	Contribution to economic development	Corruption	Fair salary	Freedom of association and collective bargaining	Health and Safety (Workers)	Migration	Respect of indigenous rights	Working time
A Forestry and Logging	0.043	0.156	0.615	2.508	2.575	1.267	3.716	1.842	0.020
A Manufacture of basic metals	0.096	2.745	1.927	3.120	2.826	0.947	1.545	0.835	0.011
A Manufacture of non-metallic mineral products	0.011	1.514	1.072	2.642	2.457	0.295	3.465	1.708	0.017
A Manufacture of paper and paper products	0.057	1.271	1.142	3.025	3.097	0.384	3.732	1.889	0.023
A Manufacture of wood and of products of wood and cork, except furniture; manufature of articles of straw and planting materials	0.080	0.188	1.063	2.967	3.117	0.561	3.247	1.660	0.021
A Mining and Quarrying	0.137	4.748	3.131	4.337	3.646	1.056	1.657	0.828	0.010
B Forestry and Logging	0.016	0.326	10.858	10.787	10.381	6.717	0.026	0.184	0.018
B Manufacture of basic metals	0.068	1.312	11.832	9.012	8.807	6.591	0.113	0.272	0.016
B Manufacture of non-metallic mineral products	0.039	1.194	10.319	8.329	7.795	1.699	0.032	0.123	0.017
B Manufacture of paper and paper products	0.059	0.130	11.772	10.593	9.821	3.681	0.094	0.292	0.033
B Manufacture of wood and of products of wood and cork, except furniture; manufature of articles of straw and planting materials	0.054	0.286	7.940	6.652	6.537	5.721	0.168	0.890	0.019
B Mining and Quarrying	0.290	0.876	14.133	11.338	11.023	4.642	0.050	0.180	0.018
C Forestry and Logging	4.264	4.191	42.700	60.495	47.432	38.231	0.066	0.901	0.218
C Manufacture of basic metals	1.279	0.702	12.910	14.339	14.337	4.699	0.051	0.277	0.031
C Manufacture of non-metallic mineral products	1.505	0.678	15.118	23.442	16.788	2.758	0.055	0.328	0.047
C Manufacture of paper and paper products	1.763	0.440	17.674	18.930	19.663	3.394	0.080	0.409	0.032
C Manufacture of wood and of products of wood and cork, except furniture; manufature of articles of straw and planting materials	1.510	0.608	15.149	16.077	16.863	2.732	0.040	0.356	0.046
C Mining and Quarrying	2.297	2.847	23.307	25.740	25.863	4.384	0.081	0.497	0.041
EU28 Forestry and Logging	0.064	0.324	1.489	1.889	2.395	2.912	0.366	0.065	0.021
EU28 Manufacture of basic metals	0.017	1.148	1.531	1.392	2.023	1.931	0.345	0.060	0.016
EU28 Manufacture of non-metallic mineral products	0.010	0.339	1.689	1.169	1.838	0.730	0.438	0.068	0.019
EU28 Manufacture of paper and paper products	0.049	0.898	0.995	1.380	1.869	0.758	0.430	0.109	0.017
EU28 Manufacture of wood and of products of wood and cork, except furniture; manufature of articles of straw and planting materials	0.007	0.119	1.131	1.112	1.408	1.647	0.430	0.059	0.018
EU28 Mining and Quarrying	0.362	10.592	14.389	9.371	11.371	11.173	5.465	0.896	0.134
D Forestry and Logging	0.094	0.645	7.418	8.012	0.966	0.265	0.104	0.081	0.073
D Manufacture of basic metals	0.189	4.583	18.771	14.795	3.361	4.517	0.438	0.287	0.118
D Manufacture of non-metallic mineral products	0.183	1.420	21.882	16.725	1.739	1.133	0.532	0.165	0.119
D Manufacture of paper and paper products	0.588	3.900	6.353	6.152	5.943	1.131	0.671	0.251	0.027
D Manufacture of wood and of products of wood and cork, except furniture; manufature of articles of straw and planting materials	0.192	1.485	18.683	16.748	2.164	8.761	0.584	0.188	0.148
D Mining and Quarrying	0.160	18.752	8.354	11.961	9.047	1.921	0.438	0.187	0.025
E Forestry and Logging	16.511	4.847	22.367	23.122	6.229	31.102	0.284	0.320	0.027
E Manufacture of basic metals	3.482	13.413	9.016	11.014	6.200	6.336	0.169	0.469	0.015
E Manufacture of non-metallic mineral products	12.090	1.646	16.529	13.916	2.226	14.450	0.047	0.160	0.018
E Manufacture of paper and paper products	11.039	3.123	14.388	15.236	3.967	14.852	0.141	0.226	0.022
E Manufacture of wood and of products of wood and cork, except furniture; manufature of articles of straw and planting materials	12.794	5.222	19.185	19.952	6.278	24.134	0.303	0.291	0.023
E Mining and Quarrying	8.378	4.951	14.128	12.006	3.653	12.363	0.068	0.162	0.015
F Forestry and Logging	0.013	0.286	0.245	3.823	3.821	1.466	0.381	3.666	0.031
F Manufacture of basic metals	0.020	1.148	1.035	4.383	4.241	1.858	0.438	3.605	0.025
F Manufacture of non-metallic mineral products	0.006	0.279	0.264	3.384	3.376	0.395	0.365	3.241	0.019
F Manufacture of paper and paper products	0.004	0.218	0.189	2.954	2.999	0.456	0.318	2.838	0.022
F Manufacture of wood and of products of wood and cork, except furniture; manufature of articles of straw and planting materials	0.001	0.196	0.138	3.254	3.277	1.214	0.340	3.230	0.021
F Mining and Quarrying	0.039	0.725	1.940	4.086	3.981	0.858	0.429	3.354	0.027

Figure 7 *Social risks of selected raw materials production sectors in EU-28 and extra-EU countries*

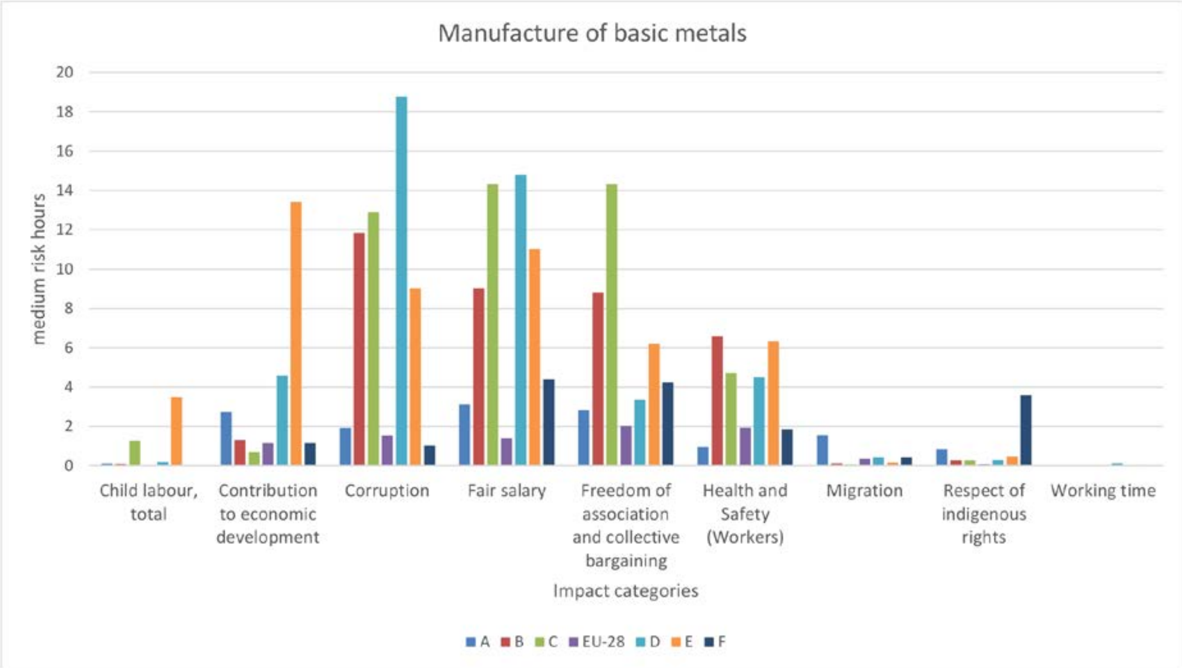

Figure 8 *Social risks regarding "Manufacture of basic metals" sector in all selected countries and in EU-28 region*

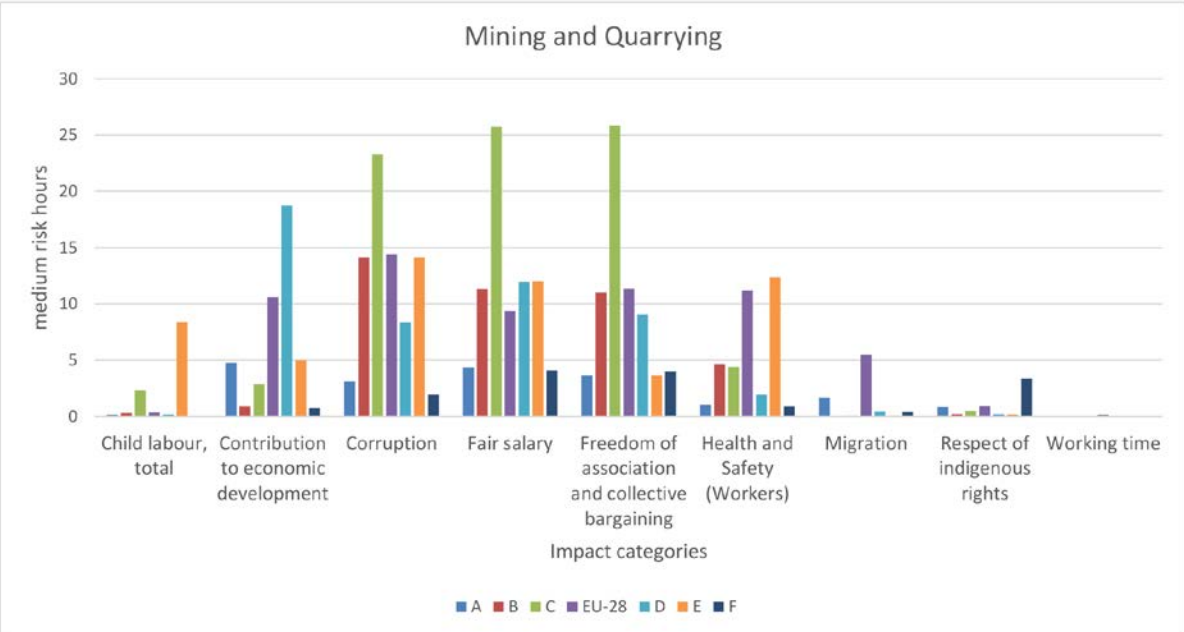

Figure 9 *Social risks regarding "Mining and quarrying" sector in all selected countries and in EU-28 region*