



POLITECNICO DI TORINO
Repository ISTITUZIONALE

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

Original

Can S-LCA methodology support responsible sourcing of raw materials in EU policy context? / Di Noi, C.; Ciroth, A.; Mancini, L.; Eynard, U.; Pennington, D.; Blengini, G. A.. - In: THE INTERNATIONAL JOURNAL OF LIFE CYCLE ASSESSMENT. - ISSN 0948-3349. - ELETTRONICO. - 25:2(2020), pp. 332-349.

Availability:

This version is available at: 11583/2813592 since: 2020-04-19T23:09:36Z

Publisher:

Springer

Published

DOI:10.1007/s11367-019-01678-8

Terms of use:

openAccess

This article is made available under terms and conditions as specified in the corresponding bibliographic description in the repository

Publisher copyright

(Article begins on next page)

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

Claudia Di Noi^{1,*}, Andreas Ciroth¹, Lucia Mancini²,
Umberto Eynard², David Pennington², Gian Andrea Blengini²

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

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

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

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

39 **1. Introduction**

40 **1.1. EU Policy context**

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

62 [2017](#)). Therefore, a continuous threat of a supply crisis is posed to the EU due to this dependence and a lack of
63 alternative materials.

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

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

92 **1.2. Motivation**

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

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

107 The research goals can be summarized as following.

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

114 **1.3. Current status of LCA in sustainability assessment of resources**

115 “Resource criticality” has emerged as a major concern in policy and research contexts ([Graedel et al. 2012](#); [EC-
116 European Commission 2010](#); [Helbig et al. 2016](#)) with an attempt to address economic importance and supply
117 risks. In recent years, a number of studies have proposed the application of Life Cycle Assessment (LCA) to
118 evaluate the impacts and the sustainability performance of the raw materials sector, highlighting the importance
119 of considering the economic and geopolitical framework when conducting evaluations ([Mancini et al. 2015](#);
120 [Sonnemann et al. 2015](#)). Raw materials and CRM are already included as flows in inventories of most common

121 databases. Furthermore, as Mancini et al. (2015) emphasise, available impact assessment methods currently
122 consider some of the criticality aspects, such as resource scarcity and contribution to environmental load.

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

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

135 **2. Methods**

136 **2.1. Approach**

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

140 Risks were quantified with selected socio-economic indicators further grouped into impact categories. The first
141 step of the work was choosing the S-LCA database for the assessment between the two currently available:
142 Social Hotspots Database (SHDB) developed by New Earth and Product Social Impact Life Cycle Assessment
143 (PSILCA) developed by GreenDelta. PSILCA was selected for the present study due to (1) more recent data
144 sources, (2) presence of an evaluation schema for data quality, and (3) provision of transparent documentation on
145 data sources and social risk levels. Once the database was defined, raw materials country-sectors and social
146 indicators were identified and aggregated among those available in PSILCA, as described in sections 2.3 and 2.4.
147 An S-LCA of six selected raw materials industries was then performed for the EU-28 region, followed by a
148 contribution analysis to detect direct and indirect impacts and investigate related supply chains. Finally, the
149 social performance of raw materials sectors in EU-28 was compared with that of six extra-EU countries to

150 highlight common and different risk hotspots. Results are presented and discussed for 1 USD output per raw
151 materials industry per region under study and include risks deriving from the upstream chain, such as supply
152 sectors for energy, equipment, and construction materials. The software openLCA was used for performing the
153 assessment; a cut-off criterion (1E-04) was applied to all calculations to be able to run them in an acceptable
154 timeframe.

155 **2.2. PSILCA database**

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

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

177 **2.3. Sector and country selection and aggregation**

178 Considering that non-energy, non-agricultural sectors are in the scope of the European policy on raw materials

179 outlined in [Section 1.1](#), available national sectors in PSILCA were aggregated to reflect the following six biotic
180 and abiotic raw materials industries in the different EU-28 countries:

- 181 - Mining and quarrying
- 182 - Manufacture of basic metals
- 183 - Manufacture of non-metallic mineral products
- 184 - Forestry and Logging
- 185 - Manufacture of paper and paper products (here called “Manufacture of paper”)
- 186 - Manufacture of wood and of products of wood and cork, except furniture; manufacture of article of
187 straw and plaiting materials (here called “Manufacture of wood”)

188 Regarding EU-28, data needed to be aggregated both on regional and sectoral level to represent the selected
189 industries in the EU-28 region. All PSILCA sectors of the 28 EU countries related to the previously chosen
190 industries were aggregated in one “EU-28” process per raw materials sector. For this purpose, the PSILCA
191 sectors were added as monetary inputs for 1 USD output (i.e. all inputs scaled to 1) per selected raw materials
192 industry. In case of sectoral aggregation, Table 1 shows that input sectors were weighted equally within the
193 countries (first factor in bold in the “Amount” column). In order to consider the contribution of the different
194 countries to the European raw materials industry, the country specific share of the total EU production for each
195 raw materials sector was taken into account and used as a weighting factor for regional aggregation ([Eurostat
196 2017](#)). This was realized with a parameter for each country, as shown by the second factor in the “Amount”
197 column in Table 1.

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

206 As no specific information was available in the database for “Forestry and Logging”, “Manufacture of wood”
207 and “Manufacture of non-metallic mineral products”, data were selected from the “Manufacture of paper” sector
208 for the first two industries and from “Manufacture of fabricated metal products, except machinery and

209 equipment” for the latter. These substitutive sectors showed the best information in terms of completeness and
210 suitability to replace the missing industries in the database. Regarding the “Mining and quarrying” sector, it was
211 not possible to isolate the non-energy mining industry because social data in PSILCA are reported for the sector
212 as whole, hence results of the study include the oil and gas sector as well.

213 **2.4. Criteria for indicator and category selection**

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

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

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

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

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

245 **3. Results**

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

254 Following these first results, the contribution of direct and indirect impacts to the overall results was analysed to
255 identify the share of risks associated with the sector itself (i.e. direct) and those originating from the upstream
256 supply chain (i.e. indirect). The contribution analysis shows that the upstream chain is often accountable for
257 social risks in EU-28 raw materials industries to a large extent. By analysing results for the mining and quarrying
258 sector in more detail, it is possible to highlight that upstream processes in the supply chain contribute more than
259 90% to most impact categories, see Figure 3. When direct and indirect impacts are investigated for the other
260 sectors, the supply chain contribution appears to be diminished in comparison with “Mining and quarrying”.
261 However, social risks deriving from upstream processes represent an important share in all categories, see for
262 instance Figure 4 for “Forestry and logging”.

263 Considering that the contribution of the supply chain to overall social risks emerged as an important finding,
264 further reflections on the geographic distribution and main sources of risks along the upstream chain appeared
265 necessary. A deeper investigation of the supply chain of different raw materials sectors in EU-28 shows that
266 significant impacts are originating in extra-EU countries, specifically in Asian countries. For instance, Figure 5
267 shows that the main social hotspots related to the indicator “Freedom of associations and bargaining rights” for

268 the sector “Forestry and Logging” in EU-28 are in China. In addition, India and a number of African countries
269 often resulted as geographic locations for many social risks occurring in the upstream chain of EU-28 raw
270 materials industries, for example in the case of the category “Fair salary” for the sector “Manufacture of basic
271 metals” in EU-28, see Figure 6. Regarding the source of risks in the supply chains of the industries under study,
272 it is possible to identify several recurring social hotspots between sectors and impact categories. Construction
273 processes in India and China, basic metals and manufacturing in India, and metal products in China can be
274 identified as the main contributing sectors to overall social risks in European raw materials industries. For
275 instance, Table 4 shows that most of the top 10 impact contributions to “Fair salary” for “Mining and quarrying”
276 in EU-28 originate in India and are associated with construction, manufacturing, and metals.

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

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

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

298 following results:

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

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

310 **4. Discussion**

311 **4.1. Strength and weakness of the study**

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

326 Social information in PSILCA is clearly the basis of the presented results. The assessment of data quality with

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

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

349 **4.2. Interpretation and context of results**

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

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

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

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

394 **5. Conclusions**

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

418 in the present article. However, the outcomes obtained with such methodological framework should be further
419 investigated at a more detailed level, for instance considering the subnational context and weaknesses of the
420 study. Limitations connected with uncertainties of results and data quality should always be reported in order to
421 preserve transparency and quality of the outcomes.

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

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

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

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

439 **6. References**

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

476 Eurostat (2017) Annual enterprise statistics for special aggregates of activities (NACE Rev. 2). [http://appsso.euro](http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do)
477 [stat.ec.europa.eu/nui/submitViewTableAction.do](http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do). Accessed 26 April 2017

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

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

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

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

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

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

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

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

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

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

499 Mancini L, Sala S, Recchioni M, Benini L, Goralczyk M, Pennington D (2015) Potential of life cycle assessment

500 for supporting the management of critical raw materials. *Int J Life Cycle Assess* 20:100–116

501 Mancini L, Vidal Legaz B, Vizzarri M, Wittmer D, Grassi G, Pennington D (2018) Mapping the role of Raw
502 Materials in Sustainable Development Goals. A preliminary analysis of links, monitoring indicators and
503 related policy initiatives. EUR 29595 EN, Publications Office of the European Union, Luxembourg, ISBN:
504 978-92-79-98482-2, doi:10.2760/933605, JRC112892

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

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

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

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

516 Sonnemann G, Gemechu ED, Adibi N, De Bruille V, Bulle C (2015) From a critical review to a conceptual
517 framework for integrating the criticality of resources into life cycle sustainability assessment. *J Clean Prod*
518 94:20–34

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

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

526 UNEP/SETAC Life Cycle Initiative (2013) The methodological sheets for subcategories in social life cycle
527 assessment (S-LCA) Authors: Aulisio D, Azuero L, Benoit C, Ciroth A, Franze J, Mazijn B, Traverso M,

528 Valdivia S, Vickery-Niederman G, [https://www.lifecycleinitiative.org/wp-content/uploads/2013/11/S-](https://www.lifecycleinitiative.org/wp-content/uploads/2013/11/S-LCA_methodological_sheets_11.11.13.pdf)
 529 LCA_methodological_sheets_11.11.13.pdf . Accessed 7 May 2019

530 World Bank (2016) Worldwide Governance Indicators. <http://info.worldbank.org/governance/wgi/#doc-intro>.
 531 Accessed 5 April 2018

532 7. Tables

533 *Table 1 Example of regional and sectoral aggregation in EU raw materials processes in PSILCA: some inputs of the process*
 534 *“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
....			

535

536 *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	$0 \leq y < 750 \rightarrow$ vlr; $750 \leq y < 1500 \rightarrow$ lr; $1500 \leq y < 2250 \rightarrow$ mr; $2250 \leq y < 3000 \rightarrow$ hr; $3000 \leq y \rightarrow$ vhr
		Rate of fatal accidents at workplace	Cases per 100,000 employees and year		$0 \leq y < 7.5 \rightarrow$ vlr; $7.5 \leq y < 15 \rightarrow$ lr; $15 \leq y < 25 \rightarrow$ mr; $25 \leq y < 40 \rightarrow$ hr; $40 \leq y \rightarrow$ vhr
		DALYs due to indoor and outdoor air and water pollution	DALYs per 1,000 inhabitants in the country	WHO 2009	$0 = y \rightarrow$ nr; $0 < y < 5 \rightarrow$ vlr; $5 < y < 15 \rightarrow$ lr; $15 < y < 30 \rightarrow$ mr; $30 < y < 50 \rightarrow$ hr; $50 \leq y \rightarrow$ 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)	$0 < y < 100 \rightarrow$ vlr; $100 \leq y < 300 \rightarrow$ lr; $300 \leq y < 600 \rightarrow$ mr; $600 \leq y < 1000 \rightarrow$ hr; $1000 \leq y \rightarrow$ vhr
		Workers affected by natural disasters	Affected persons as % of whole population between 2012 and 2014	EM_DAT – The International Disaster Database 2015	$0 \leq y < 1 \rightarrow$ vlr; $1 \leq y < 3 \rightarrow$ lr; $3 \leq y < 5 \rightarrow$ mr; $5 \leq y < 10 \rightarrow$ hr; $10 \leq y \rightarrow$ vhr
	Freedom of association and collective bargaining	Trade union density	% of employees organised in trade unions	ILOstat 2014	$20 \geq y \rightarrow$ vhr; $20 < y \leq 40 \rightarrow$ hr; $40 < y \leq 60 \rightarrow$ mr; $60 < y \leq 80 \rightarrow$ lr; $80 > y \rightarrow$ 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	$0 = y \rightarrow$ nr; $0 < y < 2.5 \rightarrow$ vlr; $2.5 < y < 5 \rightarrow$ lr; $5 < y < 10 \rightarrow$ mr; $10 < y < 20 \rightarrow$ hr; $20 \leq y \rightarrow$ vhr
	Fair salary	Living wage, per month	USD	WageIndicator 2014	$y < 100 \rightarrow$ vlr; $100 \leq y < 200 \rightarrow$ lr; $200 \leq y < 500 \rightarrow$ mr; $500 \leq y < 1000 \rightarrow$ hr; $1000 \leq y \rightarrow$ vhr
		Minimum wage, per month	USD		$1000 \leq y \rightarrow$ vlr; $500 \leq y < 1000 \rightarrow$ lr; $300 \leq y < 500 \rightarrow$ mr; $200 \leq y < 300 \rightarrow$ hr; $y < 200 \rightarrow$ vhr; if Living wage (LW) is available: $x = LW/MW$; $x < 0.5 \rightarrow$ vlr; $y > 300$ AND $0.5 \leq x < 0.9 \rightarrow$ lr; $(y \leq 300$ AND $0.5 \leq x \leq 0.9)$ OR $(y > 300$ AND $0.9 \leq x < 0.3) \rightarrow$ mr; $(y \leq 300$ AND $0.9 \leq x \leq 1.3)$ OR $(y > 300$ AND $1.3 \leq x < 1.8) \rightarrow$ hr; $(y \leq 300$ AND $1.3 \leq x \leq 1.8)$ OR $(x \geq 1.8) \rightarrow$ vhr;
		Sector average wage, per month	USD	ILOstat 2014	$0 < y < 1 \rightarrow$ vhr; $1 \leq y < 1.5 \rightarrow$ hr; $1.5 \leq y < 2 \rightarrow$ mr; $2 \leq y < 2.5 \rightarrow$ lr; $2.5 \leq y \rightarrow$ vlr
	Working time	Hours of work per employee, per week	H		$40 \leq y < 48 \rightarrow$ lr; $30 \leq y < 40$ OR $48 \leq y < 55 \rightarrow$ mr; $20 \leq y < 30$ OR $55 \leq y < 60 \rightarrow$ hr; $60 \leq y \rightarrow$ 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 → vlr; y=4 → lr; y=3 → mr; y=2 → hr; y+1 OR 0 → 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 → nr 0<y≤2.5 AND x≤ 5 → vlr; 2.5<y≤5 AND x≤ 5 → lr; 5<y≤10 AND (x≤ 5 OR 5 <y≤ 10) → mr; 10<y≤20 AND (x≤ 5 OR 10 <y≤ 15) → hr; y≥20 AND x≤ 15 → vhr
		International Migrant Stock	% (of total population)	United Nations Department of Economic and Social Affairs	0=y → nr; 0<y<2.5 → vlr; 2.5≤y<5 → lr; 5≤y<10 → mr; 10≤y<20 → hr; 20≤y → vhr
	Net migration rate	% (= per 1,000 persons)	World Factbook 2014	0=y → nr; 0<y< 2.5 → vlr; 2.5 ≤y< 5 → lr; 5 ≤y< 10 → mr; 10 ≤y< 15 → hr; 15 ≤y → vhr	
Value Chain actors	Corruption	Public sector corruption	Score (Corruption Perception Index score of the country)	Transparency International 2012	100≥y≥85 → vlr; 84≥y≥75 → lr; 74≥y≥65 → mr; 64≥y≥55 → hr; 55≥y → vhr
		Active involvement of enterprises in corruption and bribery	% of sector- related cases out of all registered foreign bribery cases	OECD 2014	0<y≤3 → vlr; 3<y≤7 → lr; 7<y≤11 → mr; 11<y≤14 → hr; 14<y → vhr
Society	Contribution to economic development	Contribution of the sector to economic development	% of GDP	UNSTAT 2015	0≤y<1 → no opportunity; 1≤y≤10 → low opportunity; 10<y≤25 → medium opportunity; 25<y → high opportunity
		Public expenditure on education	% of GDP	World Bank 2014	0≤y<2.5 → vhr; 2.5≤y<5 → hr; 5≤y<7.5 → mr; 7.5≤y<10 → lr; 10≤y → vlr
		Adult illiteracy rate (15+ years), male	% of male population	UNESCO 2014	0≤y<1 → vlr; 1≤y<4 → lr; 4≤y<8 → mr; 8≤y<15 → hr; 15≤y → 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

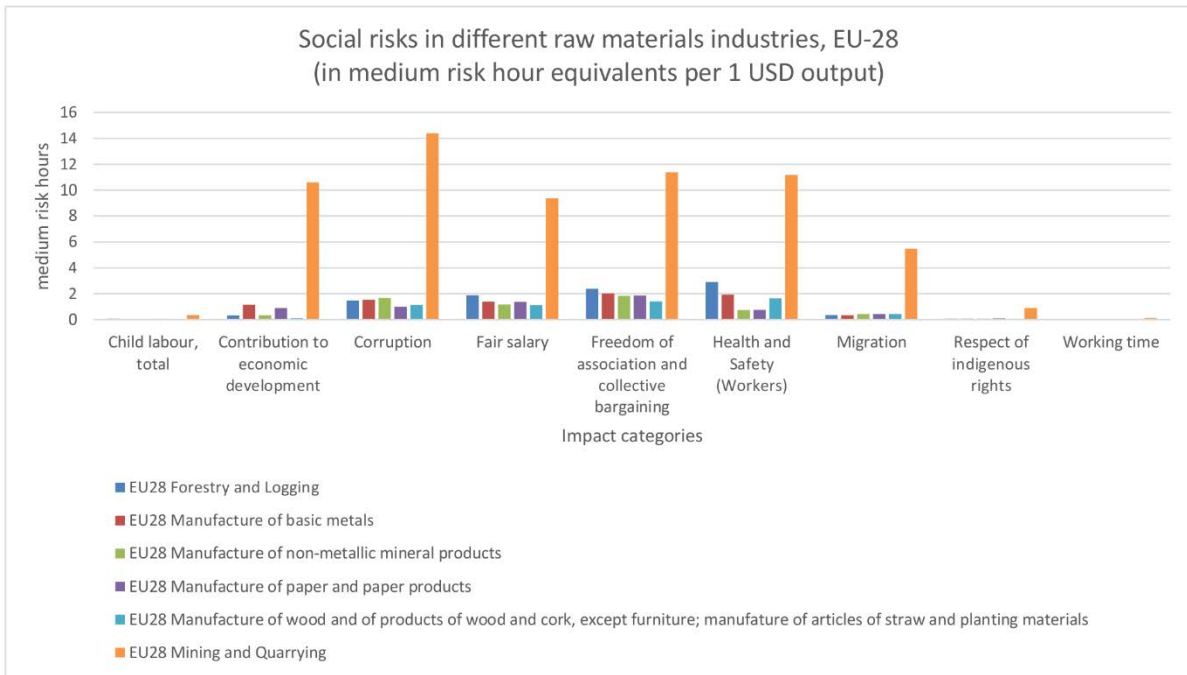


Figure 1 Social risks in different raw materials industries in EU-28

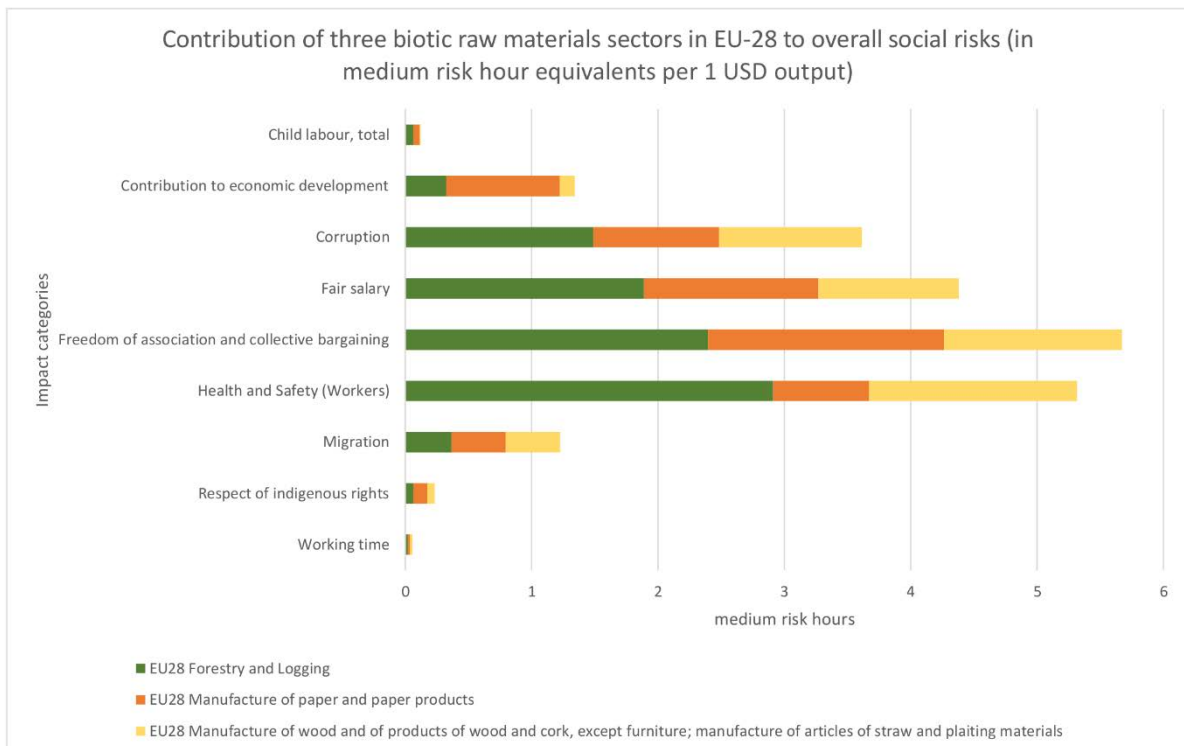


Figure 2 Contributions of three biotic raw materials sectors to total social risks of biotic raw materials production in EU-28

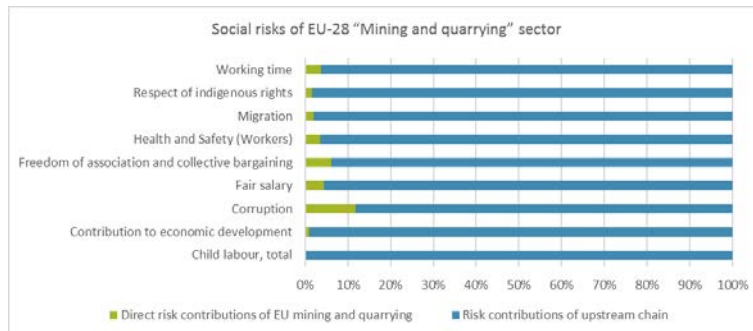


Figure 3 Relative direct (from mining industry in EU-28) and indirect (from upstream chain) contributions to final social risks of EU-28 “Mining and quarrying” sector

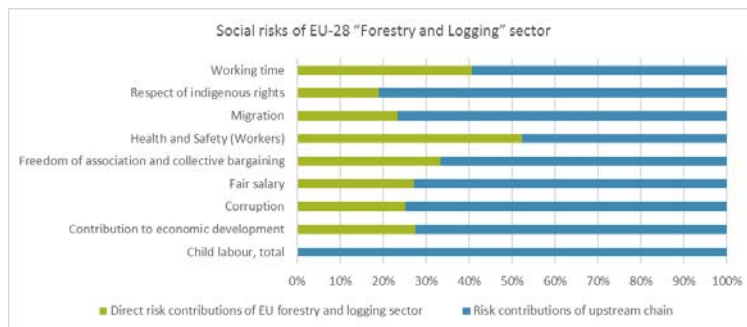


Figure 4 Relative direct (from forestry and logging industry in EU-28) and indirect (from upstream chain) contributions to final social risks of EU-28 “Forestry and logging” sector

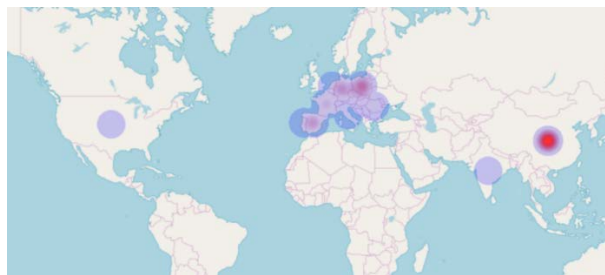


Figure 5 Main social hotspots (locations) regarding the risk of a limited freedom of association and collective bargaining of “Forestry and Logging” in EU-28 (screenshot from openLCA). Top 3 contributing locations: China, Poland, Germany

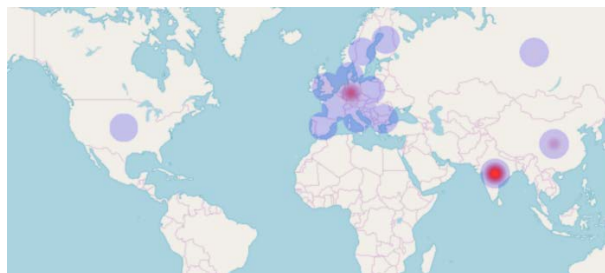


Figure 6 Main social hotspots (locations) for the category “Fair salary” of “Manufacture of basic metals” in EU-28 (screenshot from openLCA). Top 3 contributing locations: India, Germany, China

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; manufacture 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; manufacture 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; manufacture 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; manufacture 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; manufacture 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; manufacture 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; manufacture 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

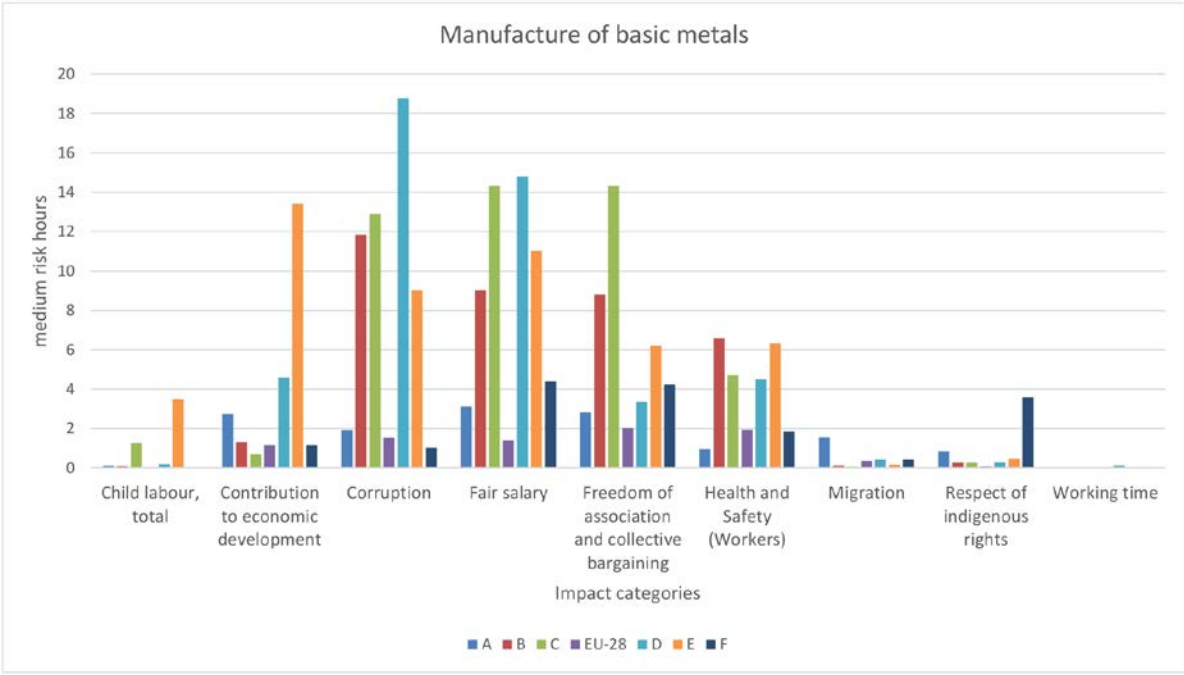


Figure 8 Social risks regarding “Manufacture of basic metals” sector in all selected countries and in EU-28 region

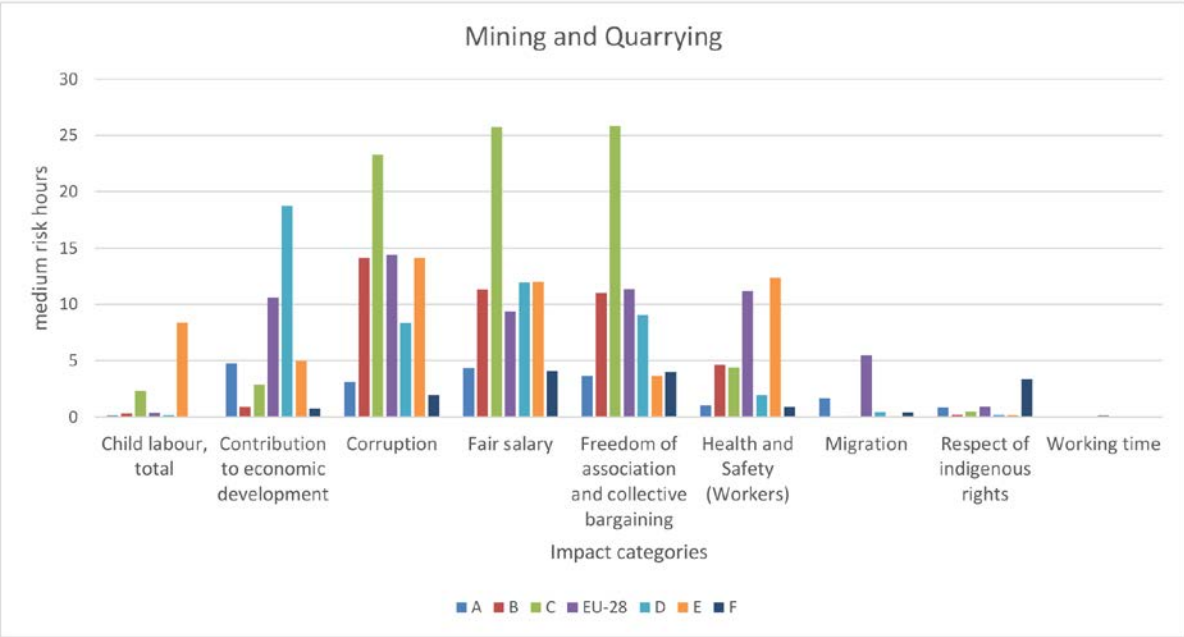


Figure 9 Social risks regarding “Mining and quarrying” sector in all selected countries and in EU-28 region