ReSilex

D7.3 – Interim social impact assessment, and public acceptance strategy toward sustainable exploitation of Silicon

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Acronyms

BSCI: Business Social Compliance Initiative

c-Si: Crystalline silicone

E-LCA: Environmental Life Cycle Assessment

EU: European Union

IEA: International Energy Agency

IFC: International Finance Corporation

ILO: International Labour Organization

ISO: International Organization for Standardization

LCC: Life Cycle Costing

mrh: medium risk hour

OECD: Organisation for Economic Co-operation and Development

PRP: Performance Reference Point

PSILCA: Products Social Impact Life Cycle Assessment

PV: Photovoltaic

R&D: Research and Development

SAM: Subcategory Assessment Method

SETAC: Society of Environmental Toxicology and Chemistry

SDG: Sustainable Development Goals

S-LCA: Social Life Cycle Assessement

UNEP: United Nations Environmental Program

USD: United States Dollar

WHO: World Health Organization

Executive Summary

This deliverable is part of Work Package 7 "Multi-faceted Impact Assessment and EU Policy Recommendations", which aims to perform a holistic life cycle assessment (Environmental Life Cycle Assessment, Life Cycle Costing, and Social Life Cycle Assessment) to assess Resilex technologies and higher commercial scales of sustainable production of Silicon and the photovoltaic (PV) modules value chain. The outcome will later use to provides recommendations for policymakers.

The objective of this interim report is to explain the selection of social impacts, social categories and sub-categories, indicators and databases and to discuss the preliminary result of social impact assessment of PV full (commercial) scale in EU.

In this regard, Social Life Cycle Assessment (S-LCA) was employed to assess the social impacts through most common photovoltaic modules supply chains in Europe. The social impacts and indicators were selected based on UNEP/SETAC guidelines and were shortlisted based on experts' consultations. The generic (hotspots) social assessment was performed through PSILCA databases where the indicators assessment method categorizes risk levels for negative indicators into a detailed spectrum. The standardized questionnaires were next developed to assess qualitatively and quantitively the selected indicators in site-specific analysis of the supply chain manufacturers.

The social aspects identified as the most negative social impacts in the generic assessment were 'bargaining rights", "fair salary" and "sanitation coverage". Also, the site-specific assessment shows potential improvement room for "community engagement improvements" and presents fewer social risks, aligning with the findings from hotspots assessments.

1. Introduction

The Importance of less dependence on fossil fuels and to move towards renewable energy sources like wind and solar energy has become a key focus in addressing challenges relevant to energy crises and environmental concerns in Europe. (Kelly et al., 2011; Hong et al., 2016; Muller et al., 2021; IRENA., 2019; and Franco & Groecer., 2021). PV technology convert solar light into electricity and photovoltaic energy sources and are referred to as clean and affordable sources of energy (IEA 2022). The main categories of PV technologies include silicon solar cells and thin-film technologies. Crystalline silicon (c-Si) modules share over 95% of global production share nowadays while thin-film PV technology covers the remaining 5 % (IEA, 2022). Highly pure silicon is the main raw material in production of solar cells whilst the required purity of silicon cannot be found in nature. The fact that the purifying industries are mainly located in China makes Silicon a geo-politically crucial metal in solar industry.

In 2008, the top ten solar PV manufacturers, based in Germany, United States, Switzerland, and Japan, accounted for over 90% of global production. However, today, all top ten manufacturers are in China, contributing to more than 70% of the global market share (IEA 2022). As the largest exporter of solar cells in the world, China is nowadays capable of covering a complete photovoltaic manufacturing chain and the country's share in manufacturing steps of solar panels (polysilicon, ingots, wafers, cells and modules) exceeds 80% of the global market. (Fu et al., 2015). Between 2013 and 2017, PV installations in Europe declined significantly. By 2021 Europe accounted for only 1% of Silicon PV module production while importing 84% of its installed needs (IEA, 2022). The global trend of PVs supply chain of different manufacturing steps for the year 2021 is presented in Figure 1.

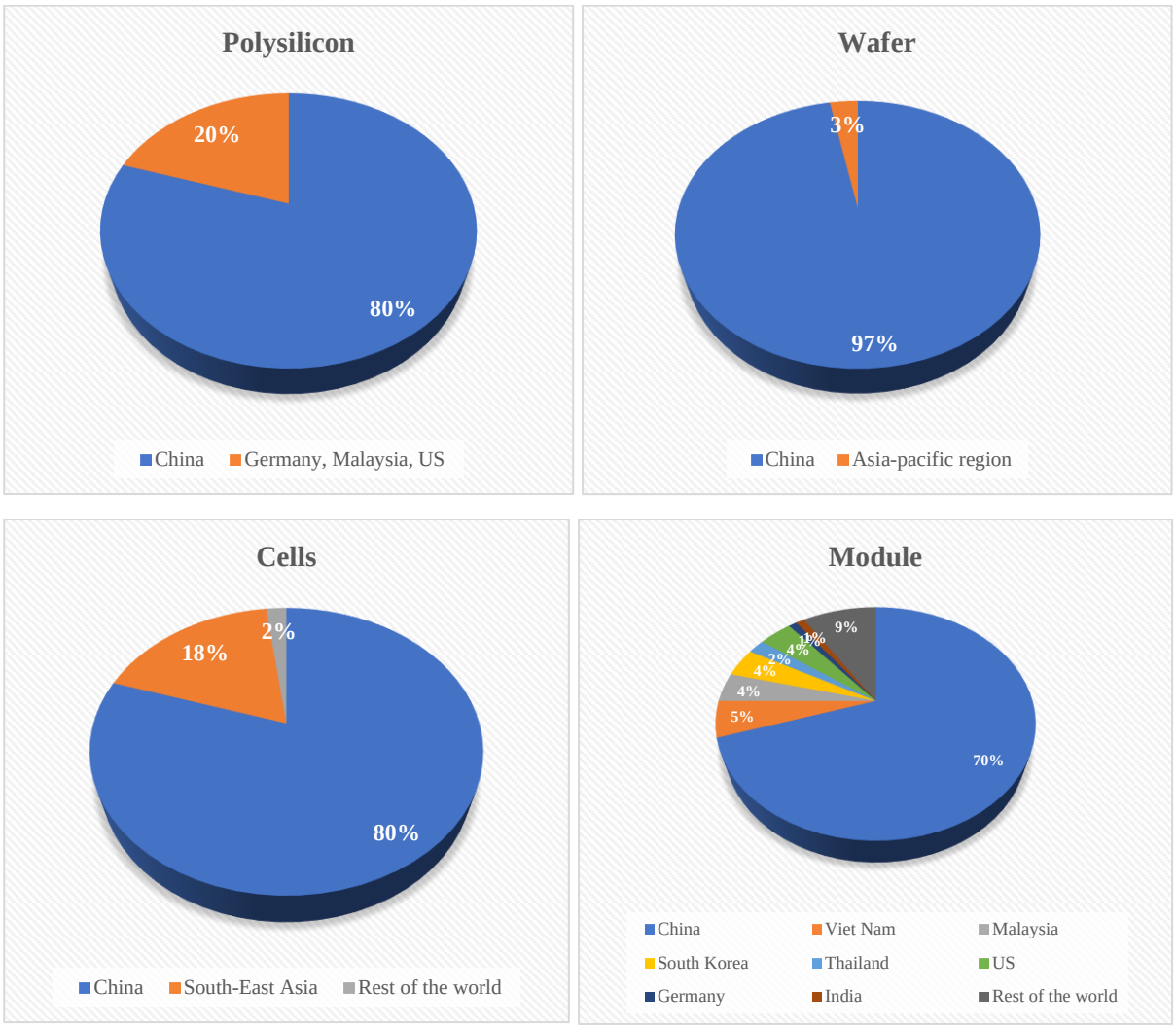

Figure 1. PV modules manufacturing steps and countries market share in 2021 (Data from IEA 2022)

Based on IEA 2022, a secure solar PV supply chain should have four main characteristics:

-*Adequacy:* having the capacity to meet the market short and long-term demand
-*Resilience:* recovery from global shocks and disruptions
-*Affordability:* staying cost-effective in national and international markets
-*Sustainability:* Addressing environmental, economic and social aspects

The recent disruptions caused by the Covid-19 pandemic and the Russia-Ukraine conflict have highlighted the urgent need for the EU market to transition toward more resilient and secure supply chains. Following evidence of human rights abuses and forced labour, the U.S. government has imposed a ban on imports from China's Xinjiang province, a key region in global solar panel production. (Masson and Kaizuka, 2022;

European Solar Manufacturing Council, 2023). Currently, Europe lacks specific legislation addressing forced labour, and as a result aside from the Chinese domestic market, the European market remains one of the primary destinations for Chinese PV products (European Solar Manufacturing Council, 2023).
The European Commission emphasizes assessing product supply chains from raw material extraction through various manufacturing processes, using three key social perspectives (European Innovation Partnership on Raw Materials, 3rd Raw Material Scoreboard, 2021). These social indicators include:

I) Responsible sourcing, aimed at ensuring a sustainable product supply while addressing both environmental and social concerns.
II) Occupational health and safety, recognizing the inherent risks in the raw material and manufacturing sectors and the need to secure safe working conditions for labourers.
III) Job creation across different manufacturing sectors, with a particular focus on advancing the transition to a circular economy.

Social acceptance refers to the acceptance level of a technology by policy makers, key stakeholders and the public (IEA, 2022). It regards points about the legal acts and regulatory framework and concerns related to creating local jobs, businesses' well-behaviour and local welfare. Greater acceptance levels could be achieved by emphasising on the added value of PV industry in terms of local job creation, and revenue generation.
Life cycle sustainability assessment composed of Environmental Life Cycle Assessment (E-LCA), Life Cycle Costing (LCC) and Social Life Cycle Assessment (S-LCA). Social life cycle assessment has been developed by United Nations (UN) to make the assessment more comprehensive. S-LCA is a framework to perform social and socio-economic impact assessment of products, technologies and services and their potential impacts on stakeholders within their life cycles (UNEP 2020). S-LCA has a slower development compared to other types of assessment mainly due to cultural and qualitative nature of some of social indicators and the resulted complexity in measuring them (Kühnen and Hahn 2017; Corona et al. 2017; Almanza & Corona., 2020). This deliverable aim to study the comprehensive application of Social Life Cycle Assessment (S-LCA) within the EU's photovoltaic sector and the current major suppliers, employing the latest PSILCA database to unveil the social hotspots in PV module supply chains. The findings can contribute to making new decision by EU policymakers and industry stakeholders, offering evidence-based recommendations to foster a more resilient and socially responsible PV manufacturing sector in Europe.

2. Methodology

In this section, the main methodology of Social LCA is explained aiming to get a clear picture of the employed framework and the different steps within the approach. The case study is also described to clarify the boundaries of the study together with data collections steps.

2.1 Social life cycle assessment

S-LCA is used to assess social sustainability of Resilex project technologies and the PV modules commercial (full) scale supply chains. In this report the PV modules full-scale has been assessed.
S-LCA perform under the same framework of Environmental LCA based on the ISO 14040-14044 framework (UNEP 2020) as suggested by the United Nations as a comprehensive approach for life cycle sustainability assessment. S-LCA follows the standardized UNEP guidelines and the methodological sheets as the main framework and consist of the four following steps:

I. Goal and scope definition: in first step, the purpose of the study is identified together with system boundaries. The potentially relevant stakeholders and impact sub-categories are specified
II. Life cycle inventory: The input and output flows are identified together with the social inventory indicators. Organizational-based data are collected on generic and site-specific levels.
III. Life cycle impact assessment: In this step potential negative or positive social impacts of the products are assessed. This will be based on organizations behaviours or activities alongside the life cycle of a product
IV. Interpretation: In this step all the previous phases of S-LCA results are analysed. The quality and consistency of the collected data together with the possible limitations are determined.

Based on the UNEP 2020 S-LCA guidelines, stakeholders within the framework are categorized into six main groups: workers, value chain actors, local community, consumers, society, and children. Each of this stakeholder category refers to a group of people in the supply chain of a product who might be affected by relevant activities within that product's life cycle stages. Impact sub-categories referred to social attributes that describe how each stakeholder group might be affected by the potential social impacts. Impact sub-categories are evaluated by inventory indicators of the collected data (quantitative, semi-quantitative, and qualitative) (Bouillas et al., 2021).

2.2 Case studies

To evaluate the social impact of full-scale photovoltaic (PV) products in the European market, two PV module supply chains were examined to compare and assess their social performance within specific system boundaries. The first supply chain pertains to PV Module A, the most traded module in the EU market, which is entirely produced in China. The second supply chain represents PV Module B, a manufacturing primarily takes within Europe. European companies involved in each production stage were selected based on their availability for the study and their production capacity. In the European supply chain, polysilicon is produced by a company in Germany, which is then shipped to a French company for ingot and wafer manufacturing. Due to the absence of large-scale cell production in Europe, the ingot and wafer products are sent to China for cell manufacturing before being re-imported to Europe for final module production by the French company.

2.2.1 Goal and scope definition

The outcome of the current social assessment is useful to reduce negative impacts of the current supply chains in the EU and propose action plans towards the European Commission ideal products supply chain (European Innovation Partnership on Raw Materials, 3rd raw material scoreboard, 2021). The system boundaries (Figure 2) include the PV lifecycle from polysilicon production to the PV module manufacturing process. The disposal stage was excluded due to data uncertainty regarding current end-of-life processes for PV modules. The functional unit considered as 1 kWp of a PV module.

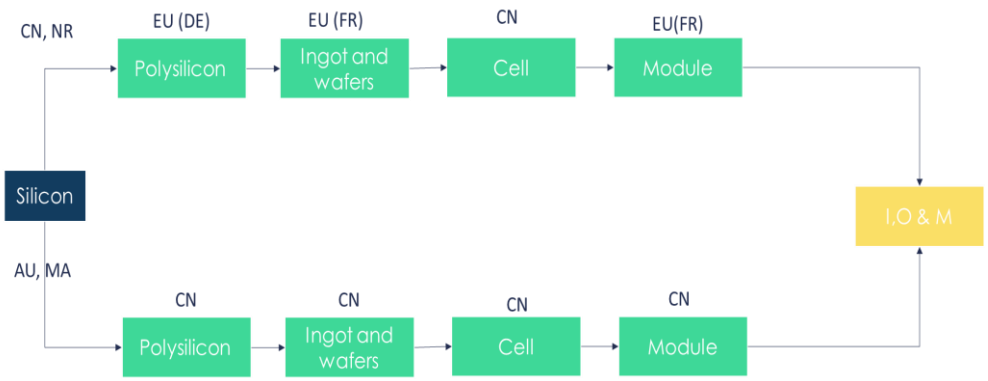

Figure 2. System boundary of the PV module (adapted after Collado et al., 2019)

This study took into consideration all the six stakeholder categories: workers, consumers, local communities, value chain actors, society, and children in the

beginning. For each of the stakeholder categories, impact sub-categories relevant to social sustainability in PV module production (i.e. labour rights, safety conditions, community impact) are analysed, However, the *consumer* category was assessed only for the companies in the last step of the supply chain where *module production* is sold. The list of considered stakeholders and social sub-categories are available in Appendix 7-1.

2.2.2 Social life cycle inventory

Data collection includes generic data for hotspots assessment, and site-specific data, for evaluating social issues at individual manufacturing sites. There are further explained in the sections below.

A) Social hot-spots data collection

The hotspots assessments for supply chains of Modules A and B were performed with PSILCA version 3.1 developed by GreenDelta GmbH. PSILCA "integrates social indicators with a global input/output model (EORA model) representing the structure of the world economy" (Mancini et al., 2018, page 31). The database plays a crucial role in detecting social hotspots by offering a detailed and measurable assessment of social risks. All of the social indicators in PSILCA database employed in this study.
The material and energy inventories for solar panel manufacturing used to perform the hotspots assessment of this study are derived from the *Life Cycle Inventories and Life Cycle Assessments of Photovoltaic Systems* report by the International Energy Agency (Frischknecht et al., 2020). with full details available in Appendix 7-4. These inventories were linked to monetary values and mapped to relevant sectors within the PSILCA database. The reference prices were obtained from the Alibaba website for bulk commercial goods (https://www.alibaba.com) and from reliable sources such as Statista (statista.com) and Our World in Data (ourworldindata.org) for energy-related sectors. Prices were adjusted to the PSILCA reference year of USD2015, accounting for inflation rates in China and other countries involved in the manufacturing stages of the PV modules. Figure 3 illustrates the model of the PV module manufacturing process as applied in PSILCA.

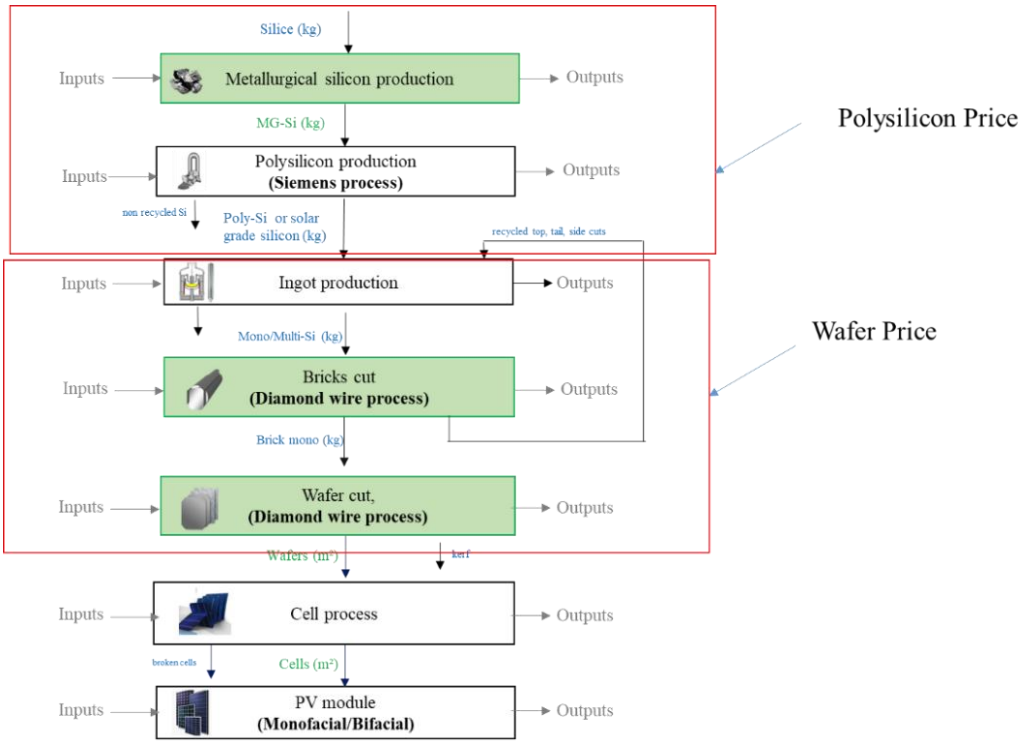

Figure 3. PV module value chain applied in hotspots assessment

The hotspots assessment of the European supply chain was performed based on the module price and the price shares within each of manufacturing steps and sourced from the same report (Frischknecht et al., 2020). The standard monetary value of European PV modules 24.8 $/Wp was considered as the final price. In cell production stage, the multi-crystalline silicon type was considered since the manufacturing of cell does not occur in Europe.

B) Site-specific data collection

The initial set of social impact sub-categories for site-specific assessment was primarily sourced from the *Methodological Sheets for Subcategories in Social Life Cycle Assessment* (UNEP, 2021) and subsequently refined through a review of relevant literature. This served as the first filtering process. Following this, two rounds of interviews were conducted to conduct the site-specific assessment, as outlined below. The first-round questionnaire aimed to identify the most pertinent social sub-categories within the photovoltaic (PV) supply chains and was distributed to a range of experts from both the academic and industrial sectors of the solar energy field. The distribution began with project partners and was extended to external experts. Based on the feedback received, the final set of social impact sub-categories was selected.

The first-round questionnaire can be found in Appendix 7-1, and the shortlisted sub-categories are presented in section 3.1.
To evaluate organizational data, the second questionnaire was specifically designed to capture the unique characteristics of the PV module supply chain. This questionnaire was distributed to key employees at various levels within selected manufacturers in the European supply chain, focusing on aspects such as organizational practices, labour conditions, and community engagement. It comprised 40 questions aligned with 32 indicators from the previously shortlisted sub-categories. These indicators were selected based on guidelines provided by UNEP (Kuhnen & Hahn, 2017; Almanza & Corona, 2020). The full questionnaire and the list of selected indicators for each sub-category can be found in Appendices 7.2 and 7.3
At present, it is virtually unattainable to collect site-specific data for the Chinese PV module due to government-imposed restrictions on companies complying with overseas transparency request (IEA, 2022). As a consequence of this restriction, no site-specific interviews have been collected for this supply chain. To ensure unified comparison with the EU PV module, a calculation of the product system of the "Electricity and steam production and supply" of the PSILCA commodity was performed and the "risk levels" were converted to the 1-4 index values of the Subcategory Assessment Method (SAM). Also, the Chinese *Cell* producer of Module B was assessed with this approach.

2.2.3 Social life cycle impact assessment

The social Impact Assessment is usually conducted with Performance Reference Point (PRP) or Impact Pathway method. The Performance Reference Point involves comparing the social performance of a product or service against predefined performance reference points (Ramirez et al., 2014). The Impact Pathway method, on the other hand, measures the inventory indicators by midpoints and endpoints indicators of UNEP and SETAC such as human capital, safety and equal opportunities (Ramirez et al., 2014).
The Performance Reference Point (PRP) has been employed in this study to conduct the impact assessment. In this regard the interview outcome of each manufacturing unit has been compared with relevant international standards.

A) Social hotspots assessment

The generic analysis of the S-LCA assesses investigated national-level indicators, e.g. freedom of association and collective bargaining, fair salary and occupational safety (Tsalidis & Posada, 2022).
The social hotspots assessment was conducted using the methodology developed in PSILCA. This methodology categorizes risk levels for negative indicators on a scale from no-risk to very-high-risk, with each level defined by specific criteria derived from internationally recognized standards. The risk assessment outcomes for each indicator are then converted to medium risk hours (mrh) by assigning numerical values to each risk level. During the PSILCA characterization step, worker-hour (representing 1 USD of process or sector output) is used as the activity variable to indicate the relevance of each unit activity. Performance reference points for assessing risk levels are selected according to the latest guidelines and standards set by reputable international organizations, such as the International Labour Organization (ILO), the World Health Organization (WHO), and the World Bank. These reference points are continuously updated to reflect current global and regional socio-economic conditions, ensuring that the assessment remains accurate and applicable (Mancini et al., 2018; Almanza & Corona, 2020).

B) Site-specific assessment

For the site-specific social impact assessment, the Subcategory Assessment Method (SAM) was applied (Ramirez et al., 2014), with performance reference points derived from widely recognized conventions and standards, including ILO conventions, the OECD Guidelines for Multinational Enterprises, the IFC Performance Standards on Social and Environmental Sustainability the ISO 26000 guidelines, and certifications such as the amfori BSCI code of conduct. The performance of organizational activities was evaluated at four levels for each social impact sub-category, with comparisons made to basic requirements. Table 1 outlines the score values assigned to each sub-category. Once the values for all indicators were determined, the organizational social performance was analysed by aggregating the SAM value points for each sub-category and stakeholder group.

Table 1. Social sub-categories value points, and their description based on SAM method

Value points	SAM levels
A=1	The organization has positive and proactive behaviour beyond the basic requirements
B=2	The organization complies with the basic requirements
C=3	The organization does not comply with the basic requirement but has a plan to do in future
D=4	The organization does not comply with the basic requirement and currently there is no plan to do it / no response was provided in the questionnaire

3. Results

In this section the results of the hotspots assessments for both supply chains of Modules A and B are presented and discussed. Site-specific results for the European supply chain are also discussed in detail and the relevant descriptive figures are presented.

3.1 Selection of social impacts

As mentioned in Methodology section, the initial shortlisting of sub-categories for this is study is based on the questionnaire distributed amongst the sector specialists. The interviewees were provided with the full list of social sub-categories and their description. The highest rated stakeholder group in this regard were ranked as, *local communities, workers, society, value chain actors and consumers.*
The social sub-categories were selected if they get %80 or higher scores from the interviewees. As for local communities; "access to material sources", "community engagement" and "local employment" have been selected as the most relevant subcategories. The highest sub-categories for worker stakeholder group were mentioned as "forced labour" and "public commitment to sustainability issues", and "contribution to economic development" and "technology development" for the *society* stakeholder group. For the *value chain actors* stakeholder group, "fair competition", "promoting social responsibility", " supplier relationship" and "wealth distribution" were ranked as highest. The *consumers* have the *"transparency"* and *"end-of-life responsibility"* as the most important and relevant social sub-categories.

3.2 Hot-spot assessment results

Figure 4 displays the PSILCA risk results for the Chinese and European PV module supply chains, highlighting notable differences in social risks between the Chinese (Module A) and European (Module B) supply chains.
A quantitative comparison of key social risk categories has been conducted to emphasize these differences. Notably, the Chinese supply chain exhibits significantly elevated risks across critical social impact sub-categories. For instance, the risk associated with "association and bargaining rights" is significantly greater for Module A (791 mrh) compared to Module B (135 mrh), underscoring major disparities in workers' ability to organize and negotiate collectively. Likewise, concerns over "fair

salary" are notably more severe in the Chinese supply chain, with Module A registering 749 mrh versus 168 mrh for Module B, reflecting substantial inequities in wages.
This trend persists across other categories, such as "minerals consumption," "pollution," and "sanitation coverage," where Module A consistently exhibits higher median risk hours. Particularly alarming are risks linked to "trafficking in persons" and "violations of employment laws and regulations" in the Chinese supply chain, with China accounting for nearly 98% of these risks. Addressing these critical issues through targeted interventions could play a crucial role in improving the social sustainability of solar electricity production.

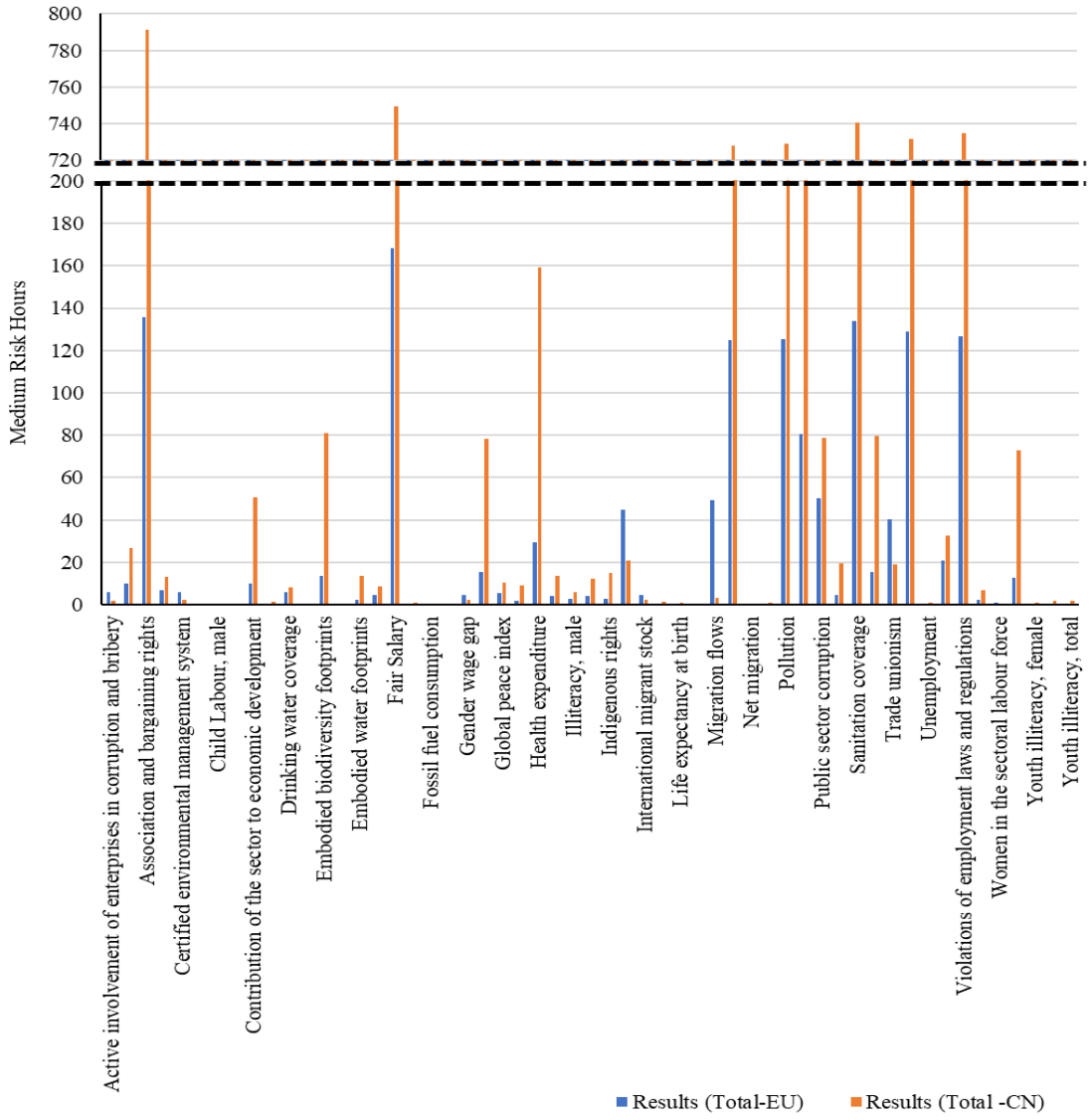

Figure 4. Hotspots assessment of Chinese and European supply chains

3.3 Site-specific preliminary results

Figure 5 presents the outcomes of the site-specific analysis of the European companies of Module B and the detailed results are presented in Appendix 7-5.
The activities of the two European companies across three manufacturing stages—polysilicon, ingot and wafer, and module production—yielded strong performance across most indicators, with more positive than negative social impacts observed. However, a key area for improvement, particularly for the company handling polysilicon production, lies in "community engagement." Currently, the lowest scores have been recorded in indicators such as "written policy on community engagement", "engaging with a diverse range of community stakeholders", and "involving them in decision-making processes". To enhance social impact, it is recommended that companies establish and implement comprehensive policies focused on community engagement and diversity inclusion. These policies should prioritize active participation from a broad spectrum of community stakeholders in decision-making.
Beyond these site-specific sub-categories, there are areas where companies have not provided responses to key indicators. For instance, within the "wealth distribution" sub-category, no information was given for indicators such as "contractual instrument within the solar panels supply chain," "invest in creating more capable suppliers and productive workers providing a foundation for sustained economic development," and "equal distribution is obtained within a fair selling price covering all the production costs where everyone returns with an acceptable profit margin."
Additionally, other important indicators, including "percentage of locals hired," "the amount company spends on local suppliers," and "companies audition on social responsibilities of the value chain actors," also lack clarification. While companies may not be obligated to disclose every operational detail in public reports, increased transparency is crucial for conducting thorough research-based evaluations.
The European company responsible for the remaining production stages (ingot, wafer, and module manufacturing) also needs to enhance its efforts in "community engagement." Specifically, improvements are required in areas such as "written policies on community engagement," "engaging with a diverse range of community stakeholder groups," "involving community stakeholders in decision-making processes," and "organizational support for community initiatives."

Beyond community engagement, greater clarification is needed for indicators within the "wealth distribution" sub-category, including "investing in creating more capable suppliers and productive workers that provide a foundation for sustained economic development" and "equal distribution is obtained within a fair selling price covering all the production costs where everyone returns with an acceptable profit margin," as no responses were provided. Similarly, in the "promoting social responsibilities" sub-

category, key indicators such as "an explicit code of conduct for protecting suppliers' human rights" and "audits regarding the social responsibility of value chain actors" remain unaddressed.

Additionally, the company reported having no established framework for "reporting the advances or barriers of the social and environmental" within the "public commitment to sustainability issues" sub-category. It also lacks "investments in technology development/technology transfer" under the "technology development" sub-category. However, the company does not engage in "membership in alliances that behave in an anti-competitive way."

The supply chain assessment values for Module A are detailed in Appendix 7-6. In general, for the Chinese supply chain (Module A), several social sub-categories indicate high or very high-risk levels. These include "social security expenditure" (absence of benefits such as family support, unemployment aid, and sickness coverage), "right of association" (workers' inability to organize and bargain collectively), "right of strike" (lack of freedom to engage in lawful protests), "violations of mandatory health and safety standards" (insufficient compliance with workplace safety regulations), "public sector corruption" (limited and insecure access to essential public services like drinking water), and environmental and social concerns such as "pollution" and "sanitation coverage."

These findings align closely with reports from Human Rights Watch (2024), which highlight that the most significant social challenges in Chinese manufacturing stem from workers' rights violations, inadequate employee benefits, and a lack of transparency in governance.

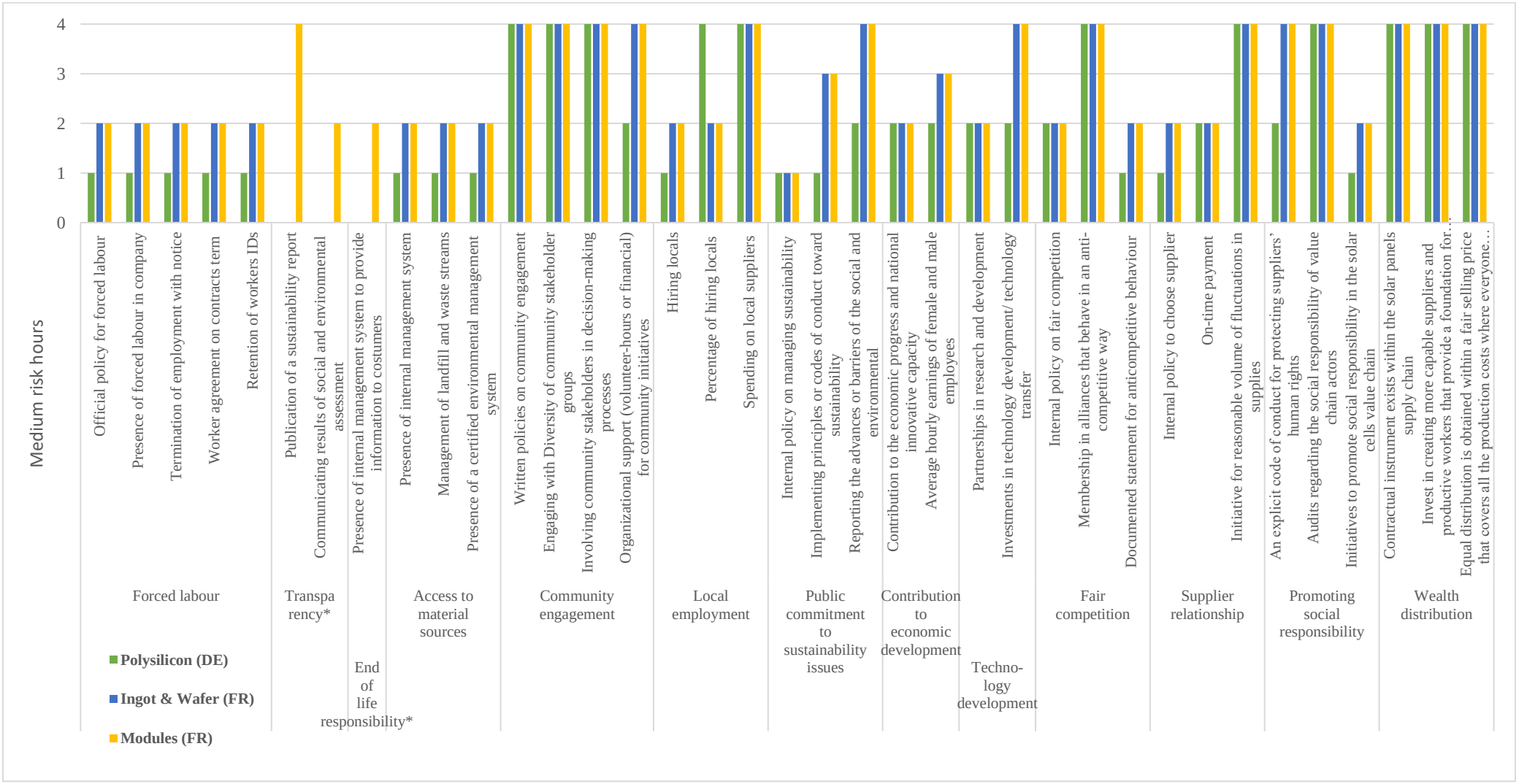

Figure 5. Site-specific results for EU supply chain

4. Conclusions

The main aim of this deliverable was to assess the social impacts of the current PV module products in Europe. As the European market dominated by Chinese modules, it is crucial addressing the social impacts of such product and to compare with European module although the European's share in the market is smaller.

As shown in the result section, the Chinese PV module supply chain has a range of highly negative social impacts such as "fair salary", "violation of employment laws regulations" and "association of bargaining rights" primarily originating from inside the country. In contrast, the European supply chain exhibit fewer negative social impacts, due to stricter social and environmental regulations. However, the results also highlight the key area of "community engagement in European" supply chain that requires improvement.

These findings suggest that while existing regulations encourage better practices, companies must take a more proactive role in improving communication and fostering stronger relationships with local communities. Research has consistently emphasized the importance of stakeholder engagement in enhancing corporate social responsibility within supply chains (Venturelli et al., 2018; Zaid et al., 2020). Our findings reinforce this perspective, underscoring the necessity for companies to move beyond basic information-sharing and adopt more comprehensive engagement strategies that prioritize meaningful interaction and responsiveness. To support this shift, EU policymakers should consider implementing incentives that encourage businesses to establish closer ties with local economies.

At the same time, the serious social challenges present in the supply chains of Chinese PV module manufacturers raise critical concerns about the long-term sustainability of these practices and their alignment with Europe's Sustainable Development Goals (SDGs). To address these issues, we recommend greater diversification in sourcing strategies and the expansion of recycling initiatives as key steps toward building a more resilient and sustainable PV module supply chain in Europe. Furthermore, European companies should develop and implement internal policies aimed at strengthening their engagement with local communities, ensuring they play a more active role in decision-making and employment opportunities.

5. Future steps

The T7.3 will continue further to assess the European PV modules technologies; the Heterojunction cells. The current technology will be regarded as a baseline scenario and will be compared to Resilex developed technologies (e.g. reduction of Silver and Indium Tin Oxide) in terms of social impacts. Therefore, we will be able to present the impacts of Eco-design solar cells. The same activity will be repeated with scenarios of Silicon recycling.

We will then apply the Quintuple Helix model to present our findings through the five group helices (academia, industries, natural environment, public and political systems) to find out the knowledge exchange amongst the helices, and contributions and improvements from each of actors to a sustainable solar supply chain within the EU.

6. References

Almanza AMH, Corona B (2020) Using Social Life Cycle Assessment to analyse the contribution of products to the Sustainable Development Goals: a case study in the textile sector. Societal LCA 25:1833–1845. https://doi.org/10.1007/s11367-020-01789-7

Bouillas G, Blanc I, Perez-Lopez P (2021) Step-by-step social life cycle assessment framework: a participatory approach for the identification and prioritization of impact subcategories applied to mobility scenarios. The International Journal of Life Cycle Assessment 26:2408–2435. https://doi.org/10.1007/s11367-021-01988-w

Corona B, Bozhilova-Kisheva K.P, Olsen SI, San Miguel G (2017) Social Life Cycle Assessment of a concentrated solar power plant in Spain: a methodological proposal. J Ind Ecol 21(6):1566–1577

Collado IM, Apra FM, Myllysilta M (2019) Smart system of renewable energy storage based on INtegrated EVs and Batteries to empower mobile, Distributed and centralised Energy storage in the distribution grid. H2020 project, European Commission.

European Solar Manufacturing Council, (2023) How to address the unsustainably low PV module prices to ensure a renaissance of the PV industry in Europe

Franco MA, Grocer, SN (2021) A Systematic Literature Review of the Solar Photovoltaic Value Chain for a Circular Economy. Sustainability 13, 9615. https://doi.org/10.3390/su13179615

Frischknecht, R, Stolz P, Krebs L, de Wild-Scholten, M, Sinha P (2020) Life Cycle Inventories and Life Cycle Assessment of Photovoltaic Systems, International Energy Agency (IEA) PVPS Task 12, Report T12-19

Fu Y, Liu X, Yua Z (2015) Life-cycle assessment of multi-crystalline photovoltaic (PV) systems in China. Journal of Cleaner Production 86:180-190. http://dx.doi.org/10.1016/j.jclepro.2014.07.057

Hong J, Chen W, Qi C, Ye L, Xu C (2016) Life cycle assessment of multicrystalline silicon photovoltaic cell production in China. Solar Energy 133: 283-293. http://dx.doi.org/10.1016/j.solener.2016.04.013

IRENA (2019) Future of Solar Photovoltaic: Deployment, investment, technology, grid integration and socio-economic aspects (A Global Energy Transformation: paper), International Renewable Energy Agency, Abu Dhabi

ISO 14040, International Standard, (2006) Environmental Management Life Cycle Assessment-Principles and Framework. (accessed March 2014).

ISO 14044, International Standard, (2006) Environmental Management Life Cycle Assessment-Requirements and Guidelines. 2014).
Kelly NA, Gibson TL (2011) Increasing the solar photovoltaic energy capture on sunny and cloudy days. Sol. Energy 85, 111–125

Kühnen M, Hahn R, (2017) Indicators in social life cycle assessment: a review of frame works, theories, and empirical experience. J Ind Eco l 21:1547–1565

Masson G, Kaizuka I. (2022) Trends in Photovoltaic Applications. REPORT IEA PVPS T1-43:2022

Mancini L, Eynard U, Eisfeldt F, Ciroth A, Blengini G, Pennington D (2018) Social assessment of raw materials supply chains. A life-cycle-based analysis, EUR 29632 EN, Publications Office of the European Union, Luxembourg. ISBN 978-92-79-99074-8, doi:10.2760/470881, JRC112626

Muller A, Freidrich L, Reichel C, Herceg S, Mittag M, (2021) Solar Energy Materials and Solar Cells. Solar Energy Materials and Solar Cells 230:111277. https://doi.org/10.1016/j.solmat.2021.111277

Ramirez P.K.S, Petti L, Haberland N.T, Ugaya C.M.L (2014) Subcategory assessment method for social life cycle assessment. Part 1: methodological framework. Int J Life Cycle Assess 19:1515–1523

Special Report on Solar PV Global Supply Chains, IEA, (2022) www.iea.org

Tsalidis G.A, Posada A (2022) Social Impact Analysis and Models. Deliverable 8.7. WaterMining Project

UNEP (2020) Guidelines for Social Life Cycle Assessment of Products and Organization. United Nations Environment Program (UNEP): https://www.lifecycleinitiative.org/library/guidelines-for-social-life-cycle-assessment-of-products-and-organisations-2020/

https://www.statista.com/ (Access: Autumn 2023)

https://ourworldindata.org/ (Access: Autumn 2023)

7. Appendix

7.1 First round interview: social sub-categories

The primary goal of this research is to conduct a Social Life Cycle Assessment (Social-LCA) for the Resilex project. The purpose of Social-LCA is to assess the social impacts of products throughout their life cycle. These social impacts encompass both direct and indirect effects of business activities on various aspects such as social equity, community development, human rights, labor rights, health, safety, education, security, and cultural diversity along the entire value chain.

In essence, Social-LCA is a methodology used to examine the potential positive and negative social impacts of products throughout their life cycle, which includes activities related to raw material extraction, processing, manufacturing, distribution, use, maintenance, recycling, and disposal.

You have been selected for participation in this study because your company is part of the PV supply chain in the EU, or you are involved in related organizations. Additionally, you hold a position that allows you to provide valuable insights into specific social issues.

The purpose of this session is to gather your perspective on the most important and relevant social sub-categories for the Resilex project, helping me understand which social impacts should be prioritized.

The findings from this interview will contribute to "Task 7.3: Social Impact Assessment, Stakeholder Analysis, and Public Acceptance" of the Resilex project. As a result of this interview and the ongoing research, you will gain a deeper understanding of your company's social sustainability performance and how to better assess it. Furthermore, I aim to provide your company with valuable insights that could help improve its social performance.

The information collected in this interview will be used exclusively for research purposes. We take the required actions to assure all the participants information and collected data provided for Resilex will be kept secure based on EU Data Protection and Privacy legal framework and in specific with the General Data Protection Regulation (GDPR) and will only be accessible to the project consortium. Results from this research will be published for academic purposes and the project deliverables only and will be referred to anonymously,

i.e. it will not be possible to trace back your organization or exclusive contribution.

Table A-2. Stakeholder groups and social sub-categories

		Relevance of social topics related to PV industries and its supply chain		
Stakeholder group	Impact subcategory	Significant relevance	No significant relevance	Comment
Local community	Delocalization and migration			
	Community engagement			
	Cultural heritage			
	Respect of indigenous rights			
	Local employment			
	Access to immaterial resources (such as education, etc.)			
	Access to material resources (such as water, minerals, etc.)			
	Safe and healthy living conditions of local community			
	Secure living conditions			
Value chain actors	Fair competition			
	Respect of intellectual property rights			
	Supplier relationships			
	Promoting social responsibility			
	Wealth distribution			
Consumers	Health and safety of consumers			
	Feedback mechanism			
	Privacy			
	Transparency			
	End-of-life responsibility			
Workers	Freedom of association & collective bargaining			
	Child labor*			
	Fair salary			
	Working hours			
	Forced labor			
	Equal opportunities			
	Health and safety of workers			
	Social benefit/social security			
	Employment relationship			
	Sexual harassment			
Society	Public commitment to sustainability issues			
	Prevention and mitigation of conflicts			
	Contribution to economic development			
	Corruption			
	Ethical treatment of animals			
	Technology development			
Children	Health issues for children as consumers			
	Children concerns regarding marketing practices			

7.2 List of studies social sub-categories and indicators

Table A-3. List of studied social sub-categories and indicators (all sub-categories employed for hotspots assessment and the blue highlighted for the site-specific assessment

Stakeholders	Subcategories	Indicators
Worker	Freedom of association and collective bargaining	Presence of union within the organization is adequately supported
		Union representatives are invited to contribute to decisions regarding working hours
	Child labour	Percentage of children employee under the legal age (14 or 15 years old)
		Records on all workers stating names and ages or dates of birth are kept on file
	Fair salary	Lowest paid worker, compared to the minimum wage / living wage
		Number of employees earning wages below poverty line
		Presence of suspicious deductions on wages
		Regular and documented payment of workers
	Working hours	Number of hours worked by employees as of filled timesheets
		Number of holidays effectively used by employees
		Fulfilment of contractual agreements concerning overtime
	Forced labour	Birth certificate, passport, identity card, work permit, or other IDs belonging to the worker are kept for safety reasons by the organization
		Workers are free to terminate their employment within the notice mentioned in contracts
		Workers agreement on contract terms; wages, working times, different types of leave
	Equal opportunities / discrimination	Ratio of men and women employed in different positions under equal conditions
		Ratio of salary of men and women based on equal salary scales
	Health & safety	Number/percentage of injuries, fatal accidents or related diseases in the organization by job
		Presence of a formal policy concerning health and safety
		Adequate general & specific occupational safety measures
		Preventive measures and emergency protocols exist regarding accidents and injuries
		Provision of first aid and medical assistance
		Education, training, counselling, prevention, and risk control programs in place to assist workforce members
	Social benefits and security	List and provide short description of social benefits provided to the workers (e.g., health insurance, pension fund, childcare, education, accommodation, etc.)
	Employment relationship	Workers has one copy of the contract
		Presence of contracts' essential elements
	Sexual harassment	Existence of clear responsibilities for matters of sexual harassment within the organization

		Efforts by the organization to reduce the risk of sexual harassment
Local community	Access to material sources	Management of landfill and waste streams
		A certified environmental management system is in place which organizations and suppliers shall meet
	Access to immaterial sources	Presence/strength of community education initiatives
		Freedom of speech and expression in the organization
	Delocalization & migration	Number of individuals who resettle attributed to the organization
		Strength of organizational procedures for integrating migrant workers into the community
	Cultural heritage	Policies in place to protect and/or support cultural heritage
		Presence of relevant organizational information to community members in their spoken language(s)
	Safe & healthy living conditions	Organization efforts to strengthen community health
		Management effort to minimize use of hazardous substances
	Respect of indigenous right	Strength of policies in place to protect the rights of indigenous community members
		Annual meetings held with indigenous community members
		Response to charges of discrimination against indigenous community members
	Community engagement	Diversity of community stakeholder groups that engage with the organization
		Number and quality of meetings with community stakeholders
		Organizational support (volunteer-hours or financial) for community initiatives
	Local employment	Percentage of workforce hired locally
		Strength of policies on local hiring preferences
		Percentage of spending on locally based suppliers
	Secure living conditions	Management policies related to private security personnel
Value chain actors	Fair competition	Membership in alliances that behave in an anti-competitive way
		Documented statement or procedures (policy, strategy etc.) to prevent engaging in or being complicit in anti-competitive behaviour
	Prompting social responsibility	Presence of explicit code of conduct that protect human rights of workers among suppliers.
		Percentage of suppliers the enterprise has audited about social responsibility in the last year
		Membership in an initiative that promotes social responsibility along the supply chain
	Supplier relationship	Supplier on time payment
		Reasonable volume fluctuations in supplies
	Respect of intellectual property rights	Use of local intellectual property
	Wealth distribution	Presence of contractual instruments within the supply /value chain that ensure the distribution of the value among the actors
		Definition of a fair price, i.e., a price that covers all the production costs and returns an acceptable profit margin;
Consumer	Health & safety	Number of consumer complaints
		Number of defects detected per production batch

		Presence of Management measures to assess consumer health and safety
		Quality of labels of health and safety requirements
		Presence of a Quality and/or Product Safety Management System such
	Feedback mechanism	Presence of a mechanism for customers to provide feedback
		Management measures to improve feedback mechanisms
	Consumer privacy	Strength of internal management system to protect consumer privacy, in genera
		Number of consumer complaints related to breach of privacy or loss of data within the last year
	Transparency	Publication of a sustainability report
		Communication of the results of social and environmental life cycle impact assessment
	End-of-life-responsibility	Presence of internal management systems ensuring that clear information is provided to consumers on end-of-life options
Society	Public commitment to sustainability issues	Presence of publicly available documents as promises or agreements on sustainability issues
		Presence of mechanisms to follow-up the realization of promises
		The organization has pledged to comply with the global compact principles and has engaged itself to present yearly; communication on progress
	Contribution to economic development	Contribution of the product/service/organization to economic progress
		Average hourly earnings of female and male employees, by occupation, age, and persons with disabilities
	Technology development	Partnerships in research and development
		Investments in technology development/ technology transfer
	Corruption	Formalized commitment of the organization to prevent corruption, referring to recognized standards
		The organization carries out an anti-corruption program
	Ethical treatment of animals	Presence/number of serious injuries, illnesses, and unforeseen fatal casualties reported by workers and animal specialists
		Complaints from consumers or civil society organizations representing animal welfare issues
		Actions in response to complaints or serious unforeseen cases putting the lives or welfare of the animals at risk
Children	Health issues for children as consumers	The organization carries out programs that provide an understanding or information about the impact of products on children's health
		The organization carries out programs to promote health impact to children
	Children concerns regarding marketing practices	The organization has a policy on responsible marketing

7.3 Site-specific interview of solar panels supply chain

I. General questions

The initial part of this questionnaire is designed to gather basic information about your company and its role within the solar cell and module supply chain.

1.1 What are the final products manufactured by your company?
1.2 What is the annual production volume of these products?
1.3 On average, what was the cost of your company's primary raw material in 2021 and 2022 (Euro per unit)?
1.4 On average, what was the selling price of your company's end products in 2021 and 2022 (Euro per unit)?

II. Site- specific questions

The second section of this questionnaires refers to working condition in your company, the company's relationship with local communities and the suppliers alongside of the supply chain and toward the society. Please answer the questions with the best of your knowledge. "The organization" term from now on refers to the company you work for.

1. Stakeholder: Workers

1.1. Forced labor

1.1.1. Does the organization have an official policy on forced labor?
Yes □ please elaborate No □ In progress □

1.1.2. Has there been any presence of forced labor in the organization?

1.1.3. Are workers in the organization free to terminate their contract within the legal notice time? If not, please explain the reasons.

1.1.4. Are workers discussed about different aspects of their contract terms prior to their hiring, e.g.: working times, different types of leaves, etc.

1.1.5. Have the workers documents (ID, passport) been ever retained by the employer during or after the hiring procedures?

2. Stakeholder: Consumers

2.1. Transparency

2.1.1. Does the organization publish a report to communicate its sustainability of social and environmental dimensions?

If yes: How would you rate the quality and comprehensiveness of the information available in the sustainability report?

2.1.2. Does the company communicate the results of the Social and Environmental life cycle assessment with its consumers?

Yes □ No □ In progress □

2.2. End of life responsibility

2.2.1. Is there internal management system in the organization to provide sound information on the end-of-life options to consumers (such as product responsibility performance indicators, return policy, recyclability of products, etc.)

Yes □ No □ In progress □

2.2.2. To the best of your knowledge, are there any labeling regulations (e.g. international certificate) that your company must comply with?

Yes □ (please name) No □ In progress □

3. Stakeholder: Local Community

3.1. Access to material sources

3.1.1. Is there any internal management system in the organization to ensure the sustainable use of natural resources and the prevention of pollution?

Yes (please elaborate) □ No □ In progress □

3.1.2. Is there any protocol or policy that company employ to manage its landfills and the waste streams?

Yes □ (please elaborate) No □ In progress □

3.1.3. Does the company comply with a particular certified environmental management system?

Yes □ (please name the certificate) No □ In progress □

3.2. Community engagement

3.2.1. Are there any written policies on community engagement at the organizational level?

Yes □ (Please elaborate) No □ In progress □

3.2.2. Which community stakeholder groups / diversity engage with the organization?

3.2.3. Does the company involve community stakeholders in decision-making processes?

Yes □ No □ In progress □

3.2.4. Does the organization offer support (volunteer-hours or financial) for community initiatives? (e.g. development of regional infrastructure or quality of life)

Yes □ No □ In progress □

3.3. Local employment

3.3.1. Is it part of the company's policy to hire local people?

Yes □ No □ In progress □

3.3.2. Around what percentage of the organization workers are from locals?

3.3.3. In your opinion, to what extent the organization spend on local suppliers (strengthen opportunities for local suppliers to contribute to value chains)?

4. Stakeholder: Society

4.1. Public commitments to sustainability issues

4.1.1. Is managing sustainability issues part of the organization's policy, strategy and goals?

Yes □ (please provide examples) No □ In progress □

4.1.2. Does the organization implement principles or codes of conduct toward sustainability?

Yes □ (please name) No □ In progress □

4.1.3. Does the organization report the advances or barriers of the social and environmental dimensions of the company's activities (e.g. in form of public reports)?

Yes □ (please elaborate) No □ In progress □

4.1.4. In case you answer" yes" to the question above, are you aware of any cases that the company's social or environmental activities have not fulfilled the mentioned initiative?

Yes □ (please elaborate) No □ In progress □

4.2. Contribution to economic development

4.2.1. Do you think the company and its products and services contribute to the economic progress and national innovative capacity of its host country (e.g. by generating and use of new technologies)?

Yes □ Somehow □ not at all □

4.2.2. On average what is the average hourly earnings of female and male employees, by occupation, age, and persons with disabilities?

4.3. Technology development

4.3.1. Does the organization participate in research and development for efficient and environmentally sound technologies as part of its strategy?

Yes□ No □ Recently started □

4.3.2. Has the organization engaged or invested in:

4.3.3. Transfer of the technical or scientific findings of the company to other companies?

Yes □ No □ To some extent □

4.3.4. Hiring educated staff (holder of Doctoral or Master degrees)

Yes □ No □ Recently started □

5. Stakeholder: Value Chain Actors (Provide answers for EU and non-EU suppliers separately)

5.1. Fair competition

5.1.1. Does the organization have a policy about competing fairly and that prevent behaving in unethical behavior?

Yes □ No □ In progress □

5.1.2. Does the company participate in alliances that behave in an anti-competitive way?

Yes□ (please name) No □ In progress □

5.1.3. Have there been efforts in the organization to present the concept of fair competition to the employees?

Yes □ No □ In progress □

5.2. Supplier relationships

5.2.1. Does the company have a policy regarding choosing a supplier? If so, please elaborate.

5.2.2. Does the company follow a standard framework for on-time payment to its suppliers?

Yes □ No □ In progress □

5.2.3. Is there any initiative in the company to deal with the reasonable volume of fluctuations in supplies?

Yes□ (please name) No □ In progress □

5.3. Promoting social responsibility

5.3.1. Is there any explicit code of conduct (in company and amongst its sub-contractors) that protects human rights of workers among its suppliers?

Yes □ No □ In progress □

5.3.2. Does the company perform audits regarding the social responsibility of value chain actors? (for instance, unannounced visit or inspection, supervising contracts)

Yes □ No □ In progress □

5.3.3. Does the company participate in initiatives that promote social responsibility in the solar cells value chain in which the company involve?

Yes □ (please elaborate) No □ In progress □

5.4. Wealth distribution

5.4.1. Is there a contractual instrument exist within the solar panels supply chain that ensure the distribution of the value among the actors?

Yes□ (please name) No □ In progress □

5.4.2. Do you think within the current supply chain in which your company is involved in, an equal distribution is obtained within a fair selling price that covers all the production costs where everyone returns with an acceptable profit margin? (please assume the last 5 years situation)

Yes□ (please name) No □ In progress □

5.4.3. Does your organization invest in creating more capable suppliers and productive workers that provide a foundation for sustained economic development?

Yes □ (please elaborate) No □ In progress □

7.4 Hot-spot assessment inventory

Table A-4. Material and energy inventory for Chinese Module A

Flows	Amount	PSILCA process	Price ($2015)
Metallurgical silicon			
Product: MG-silicon, at plant			
Electricity	1.1 E+1 kWh	Electricity and steam production and supply	0.78969
wood chips, production mix, wet, measured as dry mass, at forest road & at sawmill	3.25E-3 kg	Furniture and products of wood, bamboo, cane, palm, straw, etc.	0.000476125
hard coal coke, at plant	2.31E+1 MJ	Coal mining and processing	0.163058
graphite, at plant	1.00E-1 kg	Raw chemical materials	0.045385
charcoal, at plant	1.70E-1 kg	Coal mining and processing	0.1543107
petroleum coke, at refinery	5.00E-1 kg	Coking	0.06189
silica sand, at plant	2.70E+0 kg	Steel processing	0.184923
oxygen, liquid, at plant	2.00E-2 kg	Chemicals for special usages	0.0084
silicone plant	1.00E-11		8.4E-12
Solar grade silicon production			
Product: silicon, solar grade, modified Siemens process, at plant	Price (2021): 36.92 ¥/KG		
hydrochloric acid, 30% in H2O, at plant	1.60E+0 kg	Chemicals for special usages	9.2480
hydrogen, liquid, at plant	5.01E-2 kg	Chemicals for special usages	0.0686
sodium hydroxide, 50% in H2O, production mix, at plant	3.48E-1 kg	Chemicals for special usages	0.0024
Electricity: grid	4.90E+1 kWh	Electricity and steam production and supply	3.5177
heat, at cogen 1MWe lean burn, allocation exergy	2.88E+1 MJ	Electricity and steam production and supply	0.8898
Single-crystalline silicon production			
Product: CZ single crystalline silicon, photovoltaics, at plant			
argon, liquid, at plant	1.00E+0 kg	Chemicals for special usages	12.3775
hydrogen fluoride, at plant	1.00E-2 kg	Chemicals for special usages	0.0248
nitric acid, 50% in H2O, at plant	6.68E-2 kg	Chemicals for special usages	0.6733
sodium hydroxide, 50% in H2O, production mix, at plant	4.15E-2 kg	Chemicals for special usages	0.0003
ceramic tiles, at regional storage	1.67E-1 kg	Manufacture of other non-metallic mineral products	0.0385
lime, hydrated, packed, at plant	2.22E-2 kg	Chemical products for daily use	0.0017
Electricity at grids	3.20E+1 kWh	Electricity and steam production and supply	2.2973
natural gas, burned in industrial furnace low-NOx >100kW	6.82E+1 MJ	Manufacture and distribution of gas	0.7049

water, deionised, water balance according to MoeK 2013, at plant	4.01E+0	kg	Water production and supply	0.0022
Water, cooling, unspecified natural origin, CN	5.09E+0	kg	Water production and supply	0.0028
Single silicon wafer production				
Product: single-Si wafer, photovoltaics, at plant				
flat glass, uncoated, at plant	9.99E-3	kg	Manufacture of glass and glass products	Very low price
sodium hydroxide, 50% in H2O, production mix, at plant	1.50E-2	kg	Chemicals for special usages	0.0001
hydrochloric acid, 30% in H2O, at plant	2.70E-3	kg	Chemicals for special usages	0.0156
acetic acid, 98% in H2O, at plant	3.90E-2	kg	Chemicals for special usages	0.0129
Di propylene glycol monomethyl ether, at plant	3.00E-1	kg	Chemicals for special usages	0.2475
alkylbenzene sulfonate, linear, petrochemical, at plant	2.40E-1	kg	Chemicals for special usages	0.1941
acrylic binder, 34% in H2O, at plant	2.00E-3	kg	Chemicals for special usages	0.0021
brass, at plant	7.44E-3	kg	Raw chemical materials	0.0001
chromium steel 18/8, at plant	1.51E-3	kg	Steel-processing	0.0048
wire drawing, steel	8.95E-3	kg	Steel-processing	0.0048
Electricity at grid	4.76E+0	kWh	Electricity and steam production and supply	0.3413
natural gas, burned in industrial furnace low-NOx >100kW	4.00E+0	MJ	Manufacture and distribution of gas	0.0414
water, deionised, water balance according to MoeK 2013, at plant	5.56E+1	kg	Water production and supply	0.0031
Photovoltaic cell production				
Product: photovoltaic cell, single-Si, at plant				
metallization paste, front side, at plant	3.37E-3	kg	Manufacture of other non-metallic mineral products	1.39043
metallization paste, back side, at plant	1.11E-3	kg	Manufacture of other non-metallic mineral products	0.45797
metallization paste, back side, aluminium, at plant	5.54E-2	kg	Metal products	0.00004
ammonia, liquid, at regional storehouse	2.19E-2	kg	Chemicals for special usages	0.00813
phosphoric acid, fertiliser grade, 70% in H2O, at plant	0	kg	Chemical Fertilizers	
phosphoryl chloride, at plant	1.33E-2	kg	Chemicals for special usages	0.11478
isopropanol, at plant	1.77E-1	kg	Chemicals for special usages	0.14591
hydrochloric acid, 30% in H2O, at plant	6.29E-4	kg	Chemicals for special usages	0.00364
hydrogen fluoride, at plant	6.45E-4	kg	Chemicals for special usages	0.00160
nitric acid, 50% in H2O, at plant	0	kg	Chemicals for special usages	
sodium hydroxide, 50% in H2O, production mix, at plant	6.04E-1	kg	Chemicals for special usages	0.00423
lime, hydrated, packed, at plant	1.51E-2	kg	Chemical products for daily use	0.00116
refrigerant R134a, at plant	3.12E-5	kg	Chemicals for special usages	Very low price

nitrogen, liquid, at plant	1.15E+0	kg	Chemicals for special usages	1.15360
silane, at plant	2.91E-3	kg	Manufacture and distribution of gas	0.01176
tap water, water balance according to MoeK 2013, at user	1.71E+2	kg	Water production and supply	0.09405
electricity, medium voltage, at grid	1.77E+1	kWh	Electricity and steam production and supply	1.27068
natural gas, burned in industrial furnace low-NOx >100kW	6.08E-2	MJ	Manufacture and distribution of gas	0.62867
Photovoltaic laminate and panel production				
Product: photovoltaic panel, single-Si, at plant				
aluminium alloy, AlMg3, at plant	2.13E+0	kg	Metal Products	4.3409
copper, at regional storage	1.03E-1	kg	Metal Products	0.4254
wire drawing, copper	1.03E-1	kg	Steel-processing	1.2751
diode, unspecified, at plant	2.81E-3	kg	Steel-processing	0.3940
silicone product, at plant	1.22E-1	kg	Metal Products	0.2013
tin, at regional storage	1.29E-2	kg	Metal Products	Very low price
lead, at regional storage	7.25E-4	kg	Metal Products	0.0012
solar glass, low-iron, at regional storage	8.81E+0	kg	Manufacture of glass and glass products	0.1232
tempering, flat glass	8.81E+0	kg	Manufacture of glass and glass products	0.4031
glass fibre reinforced plastic, polyamide, injection moulding, at plant	2.95E-1	kg	Manufacture of glass and glass products	0.1375
polyethylene terephthalate, granulate, amorphous, at plant	3.46E-1	kg	Chemicals for special usages	0.3940
polyethylene, HDPE, granulate, at plant	2.38E-2	kg	Chemicals for special usages	0.0013
ethylvinylacetate, foil, at plant	8.75E-1	kg	Chemicals for special usages	4.7278
polyvinylfluoride film, at plant	1.12E-1	kg	Chemicals for special usages	1.1088
tap water, water balance according to MoeK 2013, at user	5.03E+0	kg	Water production and supply	0.0028
hydrogen fluoride, at plant	6.24E-2	kg	Chemicals for special usages	0.1548
1-propanol, at plant	1.59E-2	kg	Chemicals for special usages	0.0205
isopropanol, at plant	1.47E-4	kg	Chemicals for special usages	0.0001
potassium hydroxide, at regional storage	5.14E-2	kg	Chemicals for special usages	0.0010
soap, at plant	1.16E-2	kg	Chemicals for special usages	0.3383
corrugated board, mixed fibre, single wall, at plant	7.63E-1	kg	Chemicals for special usages	0.0026
EUR-flat pallet	5.00E-2		Furniture and products of wood, bamboo, cane, palm, straw, etc.	0.1260
Electricity, medium voltage, at grid	1.40E+1	kWh	Electricity and steam production and supply	1.0051

7.5 Site-specific results; Module B

Table A-5. Site-specific results for EU supply chain

Sub-category	Indicator	Polysilicon (DE)	Ingot & Wafer (FR)	Modules (FR)
Forced labour	Official policy for forced labour	1	2	2
	Presence of forced labour in company	1	2	2
	Termination of employment with notice	1	2	2
	Worker agreement on contracts term	1	2	2
	Retention of workers IDs	1	2	2
Transparency *	Publication of a sustainability report			4
	Communicating results of social and environmental assessment			2
End of life responsibility *	Presence of internal management system to provide information to costumers			2
				2
Access to material sources	Presence of internal management system	1	2	2
	Management of landfill and waste streams	1	2	2
	Presence of a certified environmental management system	1	2	2
Community engagement	written policies on community engagement	4	4	4
	Engaging with Diversity of community stakeholder groups	4	4	4
	Involving community stakeholders in decision-making processes	4	4	4
	Organizational support (volunteer-hours or financial) for community initiatives	2	4	4
Local employment	Hiring locals	1	2	2
	Percentage of hiring locals	4	2	2
	Spending on local suppliers	4	4	4
Public commitment to sustainability issues	Internal policy on managing sustainability	1	1	1
	Implementing principles or codes of conduct toward sustainability	1	3	3

	Reporting the advances or barriers of the social and environmental	2	4	4
Contribution to economic development	Contribution to the economic progress and national innovative capacity	2	2	2
	Average hourly earnings of female and male employees	2	3	3
Technology development	Partnerships in research and development	2	2	2
	Investments in technology development/ technology transfer	2	4	4
Fair competition	Internal policy on fair competition	2	2	2
	Membership in alliances that behave in an anti-competitive way	4	4	4
	Documented statement for anticompetitive behaviour	1	2	2
Supplier relationship	Internal policy to choose supplier	1	2	2
	On-time payment	2	2	2
	Initiative for reasonable volume of fluctuations in supplies	4	4	4
Promoting social responsibility	An explicit code of conduct for protecting suppliers' human rights	2	4	4
	audits regarding the social responsibility of value chain actors	4	4	4
	initiatives to promote social responsibility in the solar cells value chain	1	2	2
Wealth distribution	contractual instrument exists within the solar panels supply chain	4	4	4
	invest in creating more capable suppliers and productive workers that provide a foundation for sustained economic development	4	4	4
	equal distribution is obtained within a fair selling price that covers all the production costs where everyone returns with an acceptable profit margin	4	4	4
Sum		76	97	107

7.6 SAM results of Chinese supply chain

Table A-6. SAM results for Chinese supply chain

Stakeholders			Sub-categories	Risk level	SAM level
Worker		Social benefits, legal issues	Social security expenditures	High risk	4
			Evidence of violations of laws and employment regulations	Medium risk	3
		Forced labour	Frequency of forced labour	Very low risk	1
			Trafficking in persons	Very high risk	4
			Good produced by forced labour	No data	4
		Discrimination	Women in the sectoral labour force	Very low risk	1
			Men in the sectoral labour force	Very low risk	1
			Gender wage gap	No data	4
		Fair salary	Sector average wage, per month	Very low risk	1
			Living wage, per month	Medium risk	3
			Minimum wage, per month	Very high risk	1
		Freedom of association and collective bargaining	Trade union density	Medium risk	3
			Right of collective bargaining	Low risk	2
			Right of association	High risk	4
			Right of strike	Very high risk	4
		Working time	Weekly hours of work per employee	Medium risk	3
		Child labour	Children in employment, female	Very low risk	1
			Children in employment, male	Very low risk	1
			Children in employment, total	Very low risk	1
		Health and safety	Workers affected by natural disasters	High risk	4
			DALYs due to indoor and outdoor air and water pollution	Low risk	2
			Violations of mandatory health and safety standards	Very high risk	4
			Rate of non-fatal accidents at workplace	No data	4
			Rate of fatal accidents at workplace	No data	4
			Presence of sufficient safely measures	No data	4
Value chain actors		Fair competition	presence of anti-competitive behaviour or violation of anti-trust and monopoly legislation	Very low risk	1
		Corruption	Public sector corruption	High risk	4
			Active involvement of enterprises in corruption and bribery	No data	4
		Promoting social responsibility	Membership in an initiative that promotes social responsibility along the supply chain	Very high risk	4
Local community		Access to material sources	Certified environmental management systems	Very low risk	1

			Extraction of biomass (related to area)	Medium risk	
			Level of industrial water use (related to total withdrawal)	Medium risk	3
			Extraction of industrial and construction minerals	Very low risk	2
			Level of industrial water use (related to renewable water resources)	Medium risk	3
			Extraction to biomass (related to population)	Low risk	2
			Extraction of fossil fuels	Very low risk	1
			Extraction of ores	Very low risk	1
		Safe and healthy living conditions	Drinking water coverage	Low risk	2
			Pollution level of country	Very high risk	4
			Sanitation coverage	Very high risk	4
		Environmental Footprints	Embodied agricultural area footprint	No risk	1
			Number of threatened species	Very high risk	4
			Embodied water footprint	Very low risk	1
			Embodied forest area footprint	No risk	1
		Respect of indigenous right	Indigenous people rights protection index	Medium risk	3
			presence of indigenous population	Medium risk	3
		Migration	International Migrant Stock	Very low risk	1
			Net Migration rate	Very low risk	1
			Immigration rate	No data	4
			Emigration rate	No data	4
			Number of asylum seekers in relation to total population	No data	4
			International migrant workers in the sector	No data	4
		Local employment	Unemployment rate in the country	No data	4
		GHG footprints	Embodied CO2 footprints	High risk	4
			Embodied CO2-eq footprint	Medium risk	3
Society		Health and safety	Life expectancy at birth	Very low risk	1
			Health expenditure, domestic general government	Medium risk	3
			Health expenditure, out of pocket	High risk	4
			Health expenditure, total	High risk	4
			Global peace index	Medium risk	3
			Health expenditure, external resources	Very low risk	1
		Contribution to economic development	Contribution of the sector to economic development	High opportunity	1
			Illiteracy rate, female	Medium risk	3
			Public expenditure on education	Medium risk	3
			Illiteracy rate, total	Medium risk	3
			Illiteracy rate, male	Low risk	2
			Youth illiteracy rate, total	Low risk	2

			Youth illiteracy rate, male	Low risk	2
			Youth illiteracy rate, female	Very low risk	1
			Embodied value, added total	Medium risk	3 Sum: 182

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