Sector supply-chain guidance – solar energy

European Bank
for Reconstruction and Development

1. Introduction

Solar photovoltaic (PV) modules can be broadly divided into two groups: polysilicon-based modules (first generation) and thin-film modules (second generation), which consist of cadmium telluride, copper indium gallium diselenide and amorphous silicon panels. Polysilicon-based modules make up about 95 per cent of the world market and thin-film modules the remaining 5 per cent.[1] While a more advanced group of solar cells (third generation) exists, including organic, perovskite and dye-sensitised cells, their market share is very small and their future market outlook highly uncertain.[2]

As they are the dominant technology on the market, this guidance focuses on first-generation solar PV modules. Other environmental and social risks are also present in the solar PV supply chain, but state-imposed forced labour constitutes a central and high-profile concern. Companies' ability – even across an entire industry – to address this risk is highly constrained. Recommended approaches, therefore, focus on excluding suppliers implicated in state-imposed forced labour as far down the supply chain as possible.

1.1. Overview of solar manufacturing supply chain

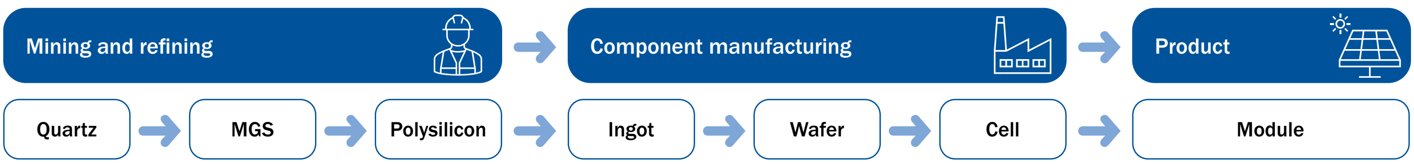
The first-generation solar PV supply chain can be divided up into materials needed to manufacture the solar cell itself and materials needed to manufacture supporting components, such as the support structure, frame, encapsulation and wiring. The following table shows the main materials used for each part.

Table 1. The main materials used in each part of the first-generation solar PV supply chain

Solar cell		Support structure	Frame, encapsulation, wiring, others
• Silicon • Silver • Germanium • Cadmium • Tellurium	• Copper • Indium • Gallium • Selenium	• Concrete (silica sand, clay, iron ore, limestone) • Steel (manganese, niobium, chromium, nickel, molybdenum, iron ore)	• Plastic (petroleum) • Glass • Aluminium (bauxite) • Copper

The value chain is depicted below.

Figure 1. The value chain for first-generation solar PV



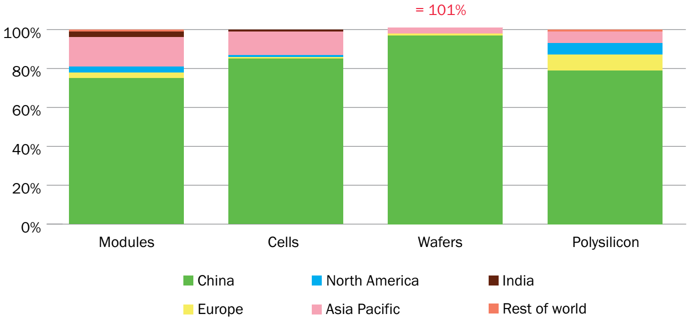
2. Supply-chain mapping and traceability

2.1. Production and supply-chain context

Over the past two decades, most of the first-generation solar PV supply chain has moved to China, where the majority of production is now hosted. Even though demand is growing worldwide, China accounts for the lion's share of the production of various components along the supply chain. The following graph represents the global breakdown of manufacturing capacity, with China producing 79 per cent of polysilicon, 97 per cent of wafers, 85 per cent of cells and 75 per cent of modules.[3] China also accounts for around 80 per cent of the production of metallurgical-grade silicon (MGS).[4] Within China, the Xinjiang Autonomous Region accounts for about 35 per cent of global polysilicon production and around 32 per cent of global MGS production.[5] While public reports indicate that 54 per cent of China's polysilicon production took place in the Xinjiang Autonomous Region in 2022,[6] this share is reportedly in decline, as production has shifted to other parts of the country, including Ningxia and Inner Mongolia.

[1] See IEA (2022a). [2] See Carrara, Alves Dias, Plazzotta and Pavel (2020). [3] See IEA (2022b). [4] See SMM (2023).
[5] See Crawford and Murphy (2023). [6] See US Department of Labor (2022).

Figure 2. Solar PV manufacturing capacity and production, by country and region, 2021



Source: IEA (2022b).

While the production of downstream components such as modules, cells and, to a lesser extent, wafers has increased outside of China, particularly in southeast Asia, this is often because Chinese companies have opened manufacturing facilities in these countries. Generally, the solar market is dominated by a relatively small number of companies, with the top five being responsible for about 70 per cent of global production. Some of these are highly vertically integrated, while others have more traditional supply chains with external suppliers.[7]

Table 2. Key control points

Polysilicon producers	The traceability of polysilicon is increasingly achievable. The market for polysilicon production consists of a relatively small number of companies, with one industry leader, Tongwei. Tongwei is expected to rapidly increase its production capacity and remain the dominant market player.[8] Four other major polysilicon producers (Daqo, Hoshine, East Hope and GCL) are on the Uyghur Forced Labour Prevention Act (UFLPA) Entity List, namely, the list of entities identified by the US government as engaging in or benefiting from forced labour involving Uyghurs and other ethnic minorities in China (goods from these entities are subject to import restrictions into the United States of America). MGS suppliers remain somewhat more opaque to the rest of the supply chain and it is not entirely clear what leverage other solar component producers have over MGS suppliers.[9]
Vertically integrated module producers	While some manufacturers struggle to attain traceability to the upstream end of the supply chain, the large, vertically integrated solar companies have far greater reach throughout the supply chain.

2.2. Traceability

Traceability of **mined minerals** is a challenge that is starting to be addressed by industry actors. For individual raw materials, certification organisations have initiated chain-of-custody standards, such as the Initiative for Responsible Mining Assurance (IRMA), the Aluminium Stewardship Initiative (ASI) and Copper Mark. However, due to the low market share of certified materials, the reach of these traceability schemes is still very low. As non-certified materials are mostly blended throughout the supply chain, it is often not possible to determine the origins of raw materials included in any product.

For **solar modules and cells**, transparency is key to mitigating forced labour risks. The development of various forced labour bans[10] has prompted many producers to develop bifurcated supply chains, whereby a company develops and operates two separate supply chains, processing different materials for final products aimed at distinct markets. One supply chain is completely traceable and is dedicated to markets with such legislation. The other supply chain is not traceable and its products are sold on all other markets.

Industry initiatives are increasingly developing protocols that aim to ensure traceability throughout the supply chain (see list below). Specific to solar supply chains, the Solar Energy Industries Association (SEIA) Solar Supply Chain Traceability Protocol indicates which data should be gathered along the supply chain. The protocol serves as guidance for increased traceability specific to the solar supply chain. It sets out specific requirements as to the types of data that should be collected by various supply-chain actors. It does not, however, provide technological or other means of delivering proof that the information provided is correct. The Solar Stewardship Initiative (SSI) has flagged the release of its traceability standard in 2024. As no details are public yet, it is not possible to assess the standard's ability to provide assurance on traceability. Generally, however, as hardly any evidence on the polysilicon, MGS and quartz stages of the supply chain is publicly available, some actors argue that such traceability claims are often not well founded.[11]

Key resources on traceability

- Solar Energy Industries Association: Solar Supply Chain Traceability Protocol
- Solar Stewardship Initiative: Supply Chain Traceability Standard (to be launched in 2024)
- IRMA chain-of-custody draft standard
- ASI chain-of-custody standard
- Copper Mark chain-of-custody standard

[7] See Crawford and Murphy (2023). [8] See Bernreuter Research (2023). [9] See Crawford and Murphy (2023).
[10] The United States has adopted the UFLPA, which establishes the rebuttable presumption that all products originating from the Xinjiang Autonomous Region include forced labour unless proof to the contrary can be provided. The European Union has imposed a similar forced labour ban. This will (pending member states' formal approval) probably come into effect in 2027.
[11] See Crawford and Murphy (2023).

2.3. Overview of potential actions to improve mapping and traceability

The key focus is on gradually improving the visibility of the supply chain to the MGS or even the quartz stage. While supplier self-assessment can be used as a basis, this information should be triangulated with publicly available sources as much as possible (such as annual reports, media reports, corporate databases and so on) to check whether the supply-chain maps provided are plausible. Also, desk research should be conducted to check for any relevant links to regions or organisations associated with forced labour. Guidance on how to conduct plausibility checks and further research in the context of state-imposed forced labour can be found here.[12]

Table 2. Examples of foundational and intermediate actions and leading practice to improve mapping and traceability

	Examples of foundational actions	Examples of intermediate actions	Examples of leading practice
Raw materials (non-cell)	Acquire bill of materials (BoM) at the level of solar PV panel supplier.	Leverage a third party (such as an industry group) to gather supplier information. Develop approaches to increase the visibility of raw materials, for example, by sourcing through a smaller number of suppliers. Start sourcing traceable materials (see standards above).	Set specific, time-bound targets to increase the amount of sourcing of traceable materials.
Solar cell	Acquire BoM at the level of solar PV panel supplier.	Together with suppliers, extend the BoM requirement to the polysilicon level. Triangulate the information provided with publicly available information to check for plausibility (for example, customs records, annual reports, company websites, corporate registries and so on). Apply traceability protocols/ standards.	Together with suppliers, extend the BoM to the MGS or even quartz level. Include the company name in local language(s), any commercial identification numbers that might apply, as well as parent companies. Triangulate the information provided with publicly available information to check for plausibility (for example, customs records, annual reports, company websites, corporate registries and so on). Apply traceability protocols/standards.

3. Supply-chain risk identification

3.1. Child labour

Child labour is not reported to be a significant risk in the **manufacturing of solar components.** It is, however, present to varying degrees in the mining of different materials needed to manufacture the supporting components of PV modules.[13]

3.2. Forced labour

There are persistent allegations in relation to labour transfer schemes in China's north-western Xinjiang province.[14] The United Nations (UN) has raised serious concerns that these constitute coercive measures.[15] The solar industry's connection to these labour schemes has been analysed in two reports published by Sheffield Hallam University,[16] which assert that all polysilicon produced in Xinjiang can be assumed to have been produced with forced labour to some extent.[17]

[12] See Sheffield Hallam University, Helena Kennedy Centre for International Justice (2023a). [13] See US Department of Labor (2023a; 2023b; 2023c). [14] See US Department of Labor (2023d). [15] See UN OHCHR (2022). [16] See Crawford and Murphy (2023) and Murphy and Elimä (2021). [17] See Murphy and Elimä (2021).

3.3. Deforestation

Deforestation is not reported as a significant risk in the manufacturing of solar components. It is, however, a prevalent concern at the raw-material stage, as mining is the fourth-largest driver of deforestation worldwide.[18]

Sources on deforestation in raw material extraction and processing
• Bauxite: European Commission study on the sustainability aspects of bauxite and aluminium (2021); IUCN National Committee of the Netherlands report on the impact of bauxite mining in Ghana's Atewa Forests (2023); Mining Magazine 2023, Mongabay 2023 • Copper: Mongabay report on copper mines in Panama (2018); Material Flows article on mining and deforestation (n.d.) • Iron ore: Reuters report on the charcoal industry in Brazil (2022); Flora and Fauna International report on forest-smart mining, including the negative effects of iron-ore mining on forests (2020) • Limestone: AP News articles on EU plans to combat deforestation (2021) • Nickel: Deutsche Gesellschaft für Internationale Zusammenarbeit report on nickel mining for the energy transition (2022); Satya Bumi report on nickel mining in Indonesia (2023); Climate Rights International report on nickel mining in Indonesia (2024); Business and Human Rights Resource Centre report on human rights and environmental abuses in southeast Asia's nickel supply chains (2023)

Utility-scale solar farms have in some cases led to deforestation,[19] whereas distributed solar projects can – even in potentially vulnerable ecosystems such as the Amazon rainforest – produce electricity without causing deforestation.[20]

3.4. Risk of harm

All **extractive industries** carry inherent risks to physical safety and health, including gender-based violence and harassment (GBVH), no matter the production country. Risks to life and limb are generally more pronounced the more informal a mining operation is. In artisanal and small-scale mining (ASM) and highly informal sectors, in particular, severe injury and death are common among miners.

During **installation and repair**, workers are at risk of electrical hazards, causing burns, blisters and other injuries. Also, where solar panels are installed on rooftops or other elevated places, workers are at risk of falls from greater heights.[21]

Sources on deforestation in raw material extraction and processing
• Bauxite: Forests & Finance article on the impact of mining on the Brazilian Amazon (2022); German Federal Ministry of Labour and Social Affairs report on potential human rights risks in energy supply chains (2023) • Copper: German Federal Institute for Geosciences and Natural Resources report on copper and cobalt mining in the Democratic Republic of the Congo (2019); German Federal Ministry of Labour and Social Affairs report on potential human rights risks in energy supply chains (2023); European Respiratory Journal article on damage to the health of artisan miners in the Democratic Republic of the Congo (2022) • Iron ore: Forests & Finance article on the impact of mining on the Brazilian Amazon (2022); Mining.com article on dust at BHP's iron-ore mines (2021); German Federal Ministry of Labour and Social Affairs report on potential human rights risks in energy supply chains (2023) • Nickel: GIZ report on nickel and the energy transition (2022); Müller and Reckordt article on human rights risks along the nickel supply chain (2017); TrendAsia article on workplace accidents in the nickel industry in Indonesia (2023); Forests & Finance article on the impact of mining on the Brazilian Amazon (2022)

3.5. Overview of potential risk identification actions

Note that audits are not effective tools for identifying risks of state-imposed forced labour, because in such settings, auditors are unlikely to be allowed to work freely, workers may fear retaliation and auditing firms may come under pressure.

[18] See Bradley (2020) and WWF (2023).. [19] See Mannion et al. (2023), Zhang et al. (2024) and Popkin (2022). [20] See Prestes (2022).
[21] See US Department of Labor (n.d.).

Table 3. Examples of actions to identify risk

	Examples of foundational actions	Examples of intermediate actions	Examples of leading practice
Non-cell components	Performing regular risk assessment for own operations and direct suppliers.	Performing risk analysis for most relevant raw materials – based on risk and spend – to verify country of origin. While traceability to mine site is usually hard to accomplish, for most raw materials, it is not always necessary in order to identify the risk. This is because within one country, the risks tend to be similar for most mines.	Sourcing specifically from mines certified by a credible certification organisation (for example, IRMA) and use audit results as grounds for a risk analysis. Sourcing from vertically integrated mining-smelting operations offering higher levels of traceability and materials segregation.
Solar cell – checking known suppliers	Verify tier 1 suppliers and manufacturing location provided in the (BoM) against Sheffield Hallam reports and US Uyghur Forced Labor Prevention Act Entity List.	Verify polysilicon suppliers and manufacturing location provided in the BoM against Sheffield Hallam reports and US Uyghur Forced Labor Prevention Act Entity List.	Verify MGS suppliers and manufacturing location provided in the BoM against Sheffield Hallam reports and US Uyghur Forced Labor Prevention Act Entity List. Triangulate the information provided with publicly available information to check for plausibility (for example, customs records, annual reports, company websites, corporate registries and so on).

4. Risk mitigation

Effective risk mitigation for the raw-materials stage is likely to include participation in industry certification schemes and multi-stakeholder initiatives. For tier 1 suppliers to a solar developer or solar contractor, a stronger focus can be placed on contractual mitigations.

4.1. Certification schemes

In the solar sector, a recent certification scheme addresses human rights risks. The Solar Stewardship Initiative (SSI) Environmental, Social and Governance (ESG) Standard provides a basic assessment against various ESG criteria, including human rights. To be effective, this standard requires independent third-party audits to be performed at the manufacturing sites where forced labour risks are present.

For many **raw materials**, certification systems have been established. These vary in governance, their ambition in terms of requirements and the scope of materials they cover.

- The Initiative for Responsible Mining Assurance (IRMA) standard: IRMA is widely recognised as the industry leader when it comes to responsible mining certifications, thanks to its multi-stakeholder governance, extensive sustainability requirements, transparency and wide scope, encompassing all mined materials.[22] It is one of the most ambitious and far-reaching standards on mined minerals. At the same time, mines can be assessed against four achievement levels, indicating an increasing level of performance: IRMA Transparency, IRMA 50, IRMA 75, IRMA 100.
- Mineral-specific certification systems: There are various certifications that cover one specific raw material, for example, the Aluminium Stewardship Initiative Performance Standard, the Responsible Steel International Standard and the Copper Mark (which, with its Joint Due Diligence Standard, also encompasses lead, molybdenum, nickel and zinc).
- Further overarching certification systems: Other standards cover various minerals and parts of the supply chain (for example, the Responsible Minerals Initiative's ESG Standard for Mineral Supply Chains and the CERA 4in1 Performance Standard (under development).

Key resources on raw materials certification systems
• German Federal Institute for Geosciences and Natural Resources (2022): Sustainability Standard Systems for Mineral Resources • Lead the Charge assessment of third-party assurance and accreditation schemes in the minerals, steel and aluminium sectors (2024)

At the raw-material level, **multi-stakeholder initiatives** aim to bring together brands, supply-chain actors, civil society and public actors. They can facilitate dialogue and help to bridge gaps between downstream expectations and upstream pushbacks, as well as between local communities and large corporate entities. Ideally, multi-stakeholder initiatives can lead to more stringent requirements at the mining and processing levels and greater willingness towards and uptake of such requirements by upstream companies. The most widely recognised initiatives are IRMA, the Responsible Minerals Initiative (RMI), the Responsible Steel Initiative (RSI) and ASI.

[22] See German Federal Institute for Geosciences and Natural Resources (2019), Lead the Charge (2024) and US Department of State (2022).

4.2. Overview of potential risk mitigation actions

Specific risk mitigation actions should be based on the results of mapping and risk identification. Given the overall risk profile of solar, the key focus area is likely to be labour issues linked to extraction activities and the risk of forced labour associated with the manufacturing of solar cells. It is important to note that the main risk is state-imposed forced labour, which companies (even across an entire industry) are unlikely to have the leverage to mitigate. In such cases, suppliers implicated in state-imposed forced labour should be excluded as far down the supply chain as possible.

Table 4. Examples of foundational and intermediate actions and leading practice in risk mitigation

	Examples of foundational actions	Examples of intermediate actions	Examples of leading practice
Child labour and forced labour – raw material extraction	Implementing a supplier code of conduct specifying zero tolerance of child labour and forced labour and setting out a commitment to the ILO Core Labour Standards, with a requirement for suppliers to cascade this to sub-suppliers. Joining an industry-led initiative on responsible business conduct. Starting to source certified materials.	Joining a multi-stakeholder initiative on responsible business conduct. Sourcing materials that are certified through an organisation with credible multi-stakeholder governance and/or sourcing materials from lower-risk geographies. Setting specific targets for the amount of certified materials to be sourced by a specific date.	Within a multi-stakeholder initiative, setting specific due diligence targets. In a certification organisation, working towards more ambitious criteria in the standard.
Forced labour – manufacturing	Implementing a supplier code of conduct specifying zero tolerance for child labour and forced labour and a commitment to the ILO Core Labour Standards, with a requirement for suppliers to cascade this to sub-suppliers. Obtain representations from suppliers that no forced labour was used in the production of the goods procured (and require suppliers to obtain such from sub-suppliers, where no direct contractual relationship). Stop sourcing from tier 1 suppliers implicated in forced labour. Where polysilicon suppliers have been implicated in forced labour, support tier 1 suppliers in moving away from these suppliers (for example, support in vetting potential new suppliers).[23]	Communicate publicly about the approach to solar supply chains, including acknowledging forced labour risks and approaches to mitigating these risks in future.	Explore possible settings in which alternative technologies, such as thin-film panels, could be used (for example, integration into buildings, particularly humid settings, utility-scale solar). Participate in the efforts of solar industry associations or other multi-stakeholder initiatives to tackle systemic issues in solar supply chains, including in relation to bifurcation.

[23] See Sheffield Hallam University, Helena Kennedy Centre for International Justice (2023b).

Key resources on mitigation actions

- OECD (2017): Practical actions for companies to identify and address the worst forms of child labour in mineral supply chains
- OECD (2013): OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas
- Re-sourcing (2021): Renewable Energy Sector – Roadmap for Responsible Sourcing of Raw Materials until 2050
- Re-sourcing (2021): Identifying Challenges & Required Actions for Responsible Sourcing in the Renewable Energy Sector
- OHCHR (2023): Business and Human Rights in Challenging Contexts Considerations for Remaining and Exiting
- Investor Alliance for Human Rights (2024): Respecting Rights in Renewable Energy

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