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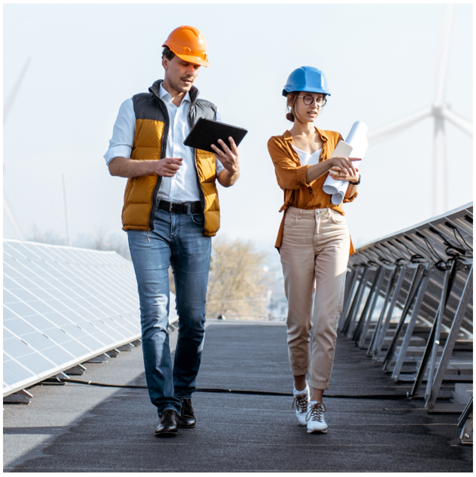
Good practices in supply chain management and carbon footprint of wind and solar energy technologies

Literature review

Alternative energy



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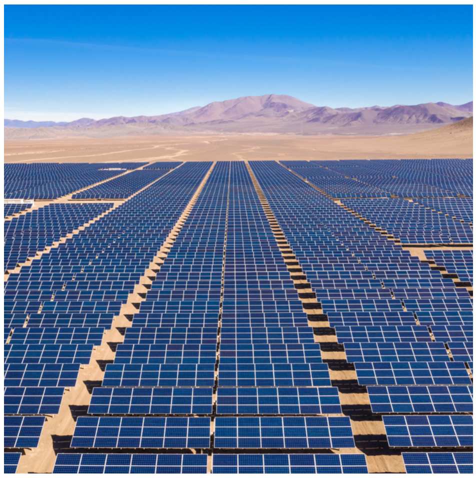

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Literature review

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Introduction

As part of Ipieca's 2021-2024 strategy, Ipieca acts as a convenor and integrator to share knowledge and good practice across oil, gas and renewables activities.

Ipieca is uniquely positioned to make a positive contribution to environmental and social performance across the energy transition. For nearly fifty years, Ipieca has been developing good practice guidance covering climate, nature, people and broader sustainability issues. This expertise can be transferred to alternative energy technologies to support scale up of a sustainable energy transition.

This literature review is based on a significant number of papers drawn from academics, solar and wind organizations, renewable companies, NGOs and other stakeholders.

The purpose of this document is to:

1. Provide a comprehensive review of existing good practices that address environmental and social risks across the supply chain throughout the project life cycle, and carbon footprint management across the project life cycle related to onshore and offshore wind and PV solar technologies
2. Identify gaps in existing knowledge and work
3. Provide Ipieca with recommended next steps

At least 165 countries have set renewable energy targets, and almost all the major oil and gas corporations have pledged to incorporate more renewables into their energy portfolio (Ren21, 2021). PV solar and wind technologies produce 13 to 96 times fewer GHG emissions than coal power plants, and 6 to 52 times fewer GHG emissions than natural gas plants (UNECE, 2021). *[See Appendix 1: Environmental and economic benefits of solar and wind energy]*

Meeting the increasing demand for access to safe, clean and affordable energy, while simultaneously curbing emissions from global energy production and use will require a broad range of solutions. The scale up of alternative energies is necessary if we are to meet the goals of the Paris Agreement, however, this scale up needs to take into account climate, environmental and social risks associated with their development and use.

The findings of this literature review will be assessed by Ipieca's Alternative Energy Task Force to define where Ipieca can add value (see recommendations on page 8). Future work for Ipieca could take the form of:

- Good practice guidance, practitioner note/tool, checklist, case study
- Awareness brief to raise awareness and share industry good practice on a particular issue (for industry and stakeholders)
- Peer learning session between members, other companies in wind/solar or other sectors
- Convening stakeholders to assess, understand and identify opportunities on a particular issue e.g. webinars, workshops

Part one: Supply chain management for wind and solar

SUPPLY CHAIN RISKS FOR WIND AND SOLAR

A summary of the risks identified during this literature review is given in Table 1. Further information on these risks can be found in Appendices 2-5.

Table 1: Supply chain risks for wind and solar

Sourcing	Poor working conditions, human rights violations, financing of conflicts, corruption, lack of transparency, child labour, forced labour, other labour issues, community and safety issues, gender and other discrimination, displacement of indigenous communities, heavy metal toxicity, waste, water stress/contamination, biodiversity risks, habitat loss and fragmentation, forest loss and degradation. *[See Appendix 2: Sourcing risks]*
Manufacturing and construction	Conflict with farmers and communities over land use, erosion, sedimentation, construction noise, biodiversity risks, habitat loss/degradation/fragmentation, water stress and chemical contamination (fluorine, chromium), human rights violations, labour issues, community and safety issues, displacement of indigenous communities. *[See Appendix 3: manufacturing and construction risks]*
Operation	Human rights violations, labour issues, community and safety issues, collision, displacement, habitat changes, impact on bird migration patterns, electromagnetic field impact on crustaceans, biodiversity risks, water stress/contamination, impact on fishing communities. *[See Appendix 4: Operation risks]*
End of life	Solid/hazardous waste and associated health and environmental impacts, ecological damage, noise, land use competition (especially for agricultural land), degradation of vegetation, biodiversity risks, water stress/contamination, thermal and air pollution, habitat fragmentation, impacts on: marine mammals, subtidal benthos, commercial fisheries, landscape/visual, physical processes (changes to sediment movements, mobilisation of contaminants, etc.), benthic ecology (habitat loss, impact of noise on fish and marine mammals, etc.). *[See Appendix 5: End-of-life risks]*

ENVIRONMENTAL AND SOCIAL RISK MANAGEMENT GUIDANCE

Academics, NGOs, standard setters, trade associations and other organizations have produced guidance documents for minimising environmental and social risks across the supply chain. *[See Appendix 6: Guidance for supply chain management]*

These documents include suggestions for:

- Responsible sourcing *[See Appendix 7: Responsible sourcing]*
- Recycling and circularity *[See Appendix 8: Good practices for recycling and circularity]*
- Impact assessments and data collection *[See Appendix 9: Impact assessments and data good practices]*
- Agrivoltaics *[See Appendix 10: Agrivoltaics]*
- Social risks *[See Appendix 11: Guidance for addressing social risks]*

This guidance is particularly strong in its coverage of social risks, such as human rights and child labour. Almost all solar and wind companies have policies and tools to deal with these social risks, especially because well-structured guidance is available. Some solar and wind companies are already taking actions to manage social and environmental risks within the supply chain. *[See Appendix 12: Actions taken by renewables companies to manage environmental and social risks]*

GAPS IN GUIDANCE FOR SUPPLY CHAIN MANAGEMENT FOR WIND AND SOLAR

But there are gaps in guidance, particularly in the following areas:

- Heavy metal toxicity, soil and groundwater acidification and habitat loss and fragmentation in the sourcing stage
- Sedimentation (relevant to offshore wind farms), chemicals, habitat loss, degradation and fragmentation in the manufacturing and construction stage
- Impact on bird migration patterns and electromagnetic field impacts on crustaceans in the operational stage
- Land use risks are widely covered by the good practice for the solar industry, but there is little guidance for the wind industry
- Apart from the risks associated with solid waste and hazardous waste, good practice guidance does not cover the wider environmental and social risks (ecological damage, noise and health) within the supply chain in the end-of-life and decommissioning stage for both solar and wind technologies.
  - Risks associated with solar energy that are not addressed by good practice guidance are land use competition (mostly for agricultural land), degradation of vegetation, biodiversity loss, water pollution, soil contamination, thermal and air pollution and habitat fragmentation.
  - Risks associated with wind energy such as water stress and contamination, biodiversity risks, noise and impacts on landscape and visuals are minutely covered by the report of the World Bank Group (2015). However, risks associated especially with offshore wind farms, such as the impacts on physical processes, marine mammals, subtidal benthos, commercial fisheries, and benthic ecology, are not covered by any good practices guidance.

Part two: Carbon footprint management for wind and solar

CARBON FOOTPRINT OF WIND AND SOLAR

Despite research suggesting that there is little-to-no carbon footprint during the operational phases of solar and wind energy, there is a carbon footprint associated with sourcing, constructing and decommissioning solar panels and wind turbines. Making steel requires the combustion of metallurgical coal in blast furnaces, and mining metals and rare earth elements is energy-intensive (Helman, 2021). The carbon emissions associated with steel and cement/concrete are significant: steel creates approximately 1.5 tonnes of carbon emissions for every 1 ton of the metal produced, and concrete production accounts for as much as 8 per cent of world CO_2 emissions (Ramsden, 2020). About 60-70 per cent (with some literature suggesting up to 98 per cent) of the total life cycle carbon emissions of wind farms and PV solar are emitted during the raw materials extraction, manufacturing, installation and construction phases (NREL, 2022; Thomson & Harrison, 2015). *[See Appendix 13: Carbon footprint of wind and solar technologies]*

The most significant impacts of wind and solar on Global Warming Potential (GWP) come from raw material acquisition and manufacturing, followed by installation, operation, and maintenance. GHG emissions associated with the life cycle of solar and wind power systems have decreased significantly during the past two decades, reaching 38.88 gCO_2eq/kWh (reducing from an average of 62 gCO_2eq/kWh since 2005), perhaps because of increased awareness of sustainability practices, responsible sourcing, innovation, recycling and circularity (Marashli et al., 2022).

REDUCING THE CARBON FOOTPRINT OF WIND AND SOLAR

Good practice in managing wind and solar so as to reduce their carbon footprint involves a number of factors.

Magnitude of the installation of solar and wind energy systems. Large, high-capacity wind and solar projects produce much fewer GHGs per unit of power. *[See Appendix 14: Opportunities to reduce the carbon footprint of solar and wind technologies]*

Lifespan of the project. Because the majority of GHGs for PV solar and wind are produced during the extraction, manufacturing and installation processes, the lifespan of solar and wind energy systems also significantly affects GHG emissions. Therefore, the GHG emissions across the entire life cycle are lower the longer the life of a project (Hamed & Alshare, 2022). *[See Appendix 14: Opportunities to reduce the carbon footprint of solar and wind technologies]*

Location of wind projects. While offshore wind projects have a higher carbon footprint than their onshore counterparts, due to their requirements around cabling and construction and use of vessels for transportation, this difference is frequently offset by the greater wind resource, which results in a higher yield of renewable electricity and, as a result, a nearly identical energy payback period (Kaldelis & Apostolou, 2017). *[See Appendix 14: Opportunities to reduce the carbon footprint of solar and wind technologies]*

Manufacturing. Both for wind and solar, the manufacturing phase accounts for most emissions. The optimisation of the structural design and the efficient application of raw materials are suggested as effective measures to improve the environmental performance of solar and wind energy (Xu et al., 2018). Additionally, the use of sustainable materials such as green steel could reduce the carbon footprint. Diversification of supply chains and the decarbonisation of the power sector could also rapidly reduce their emissions (IEA, 2022). *[See Appendix 14: Opportunities to reduce the carbon footprint of solar and wind technologies]*

Solar energy land use. To prevent a major increase in the life cycle emissions from terrestrial carbon losses, coordinated planning and control of future solar energy infrastructure should be in place. By implementing land management techniques that allow carbon sequestration in land used by solar energy projects, the terrestrial portion of the solar energy life cycle emissions could be completely avoided. Land requirements for reaching certain levels of electricity penetration with solar energy are about a magnitude lower than land requirements to meet those same levels with bioenergy (Van de Ven et al., 2021). Land requirements and the associated environmental impacts for solar and wind energy remain understudied in the literature from a quantitative point of view. *[See Appendix 14: Opportunities to reduce the carbon footprint of solar and wind technologies]*

Recycling, life extension and innovation. When compared to component manufacturing using primary raw materials, recycling wind turbines at the end of their lives can save at least 30-35 per cent of carbon emissions equivalent per kWh (Bang, et al., 2019). It is also possible to recover 90.7 per cent of the PV waste resulting from 95 GW worth of solar PV at end of life (Prabhu et al., 2021). Innovation in green steel may be key to reducing the carbon footprint of wind and solar systems (Helman, 2021). Innovation and technology for the wind industry is relatively more advanced as compared to the solar industry. What would be crucial for both the industries is supporting research in material recycling of composite waste as well as working with partners and within the industry to find new solutions for recycling and reuse. *[See Appendix 14: Opportunities to reduce the carbon footprint of solar and wind technologies]*

GAPS IN GUIDANCE FOR CARBON FOOTPRINT MANAGEMENT FOR WIND AND SOLAR

While there are several good practices and standards that suggest how to accurately measure the carbon footprint through life-cycle analysis (LCA) for renewable energy, there is not enough guidance to help minimise the carbon footprint of renewable power generation projects and initiatives. However, a variety of studies provide policy implications and recommendations to reduce the carbon emissions from solar and wind farms, which can be utilised to prepare good management practices for the stakeholders. Good practice guidance can also be drawn from government reports, international organizations such as the United Nations Environment Programme (UNEP), United Nations Framework Convention on Climate Change (UNFCCC) and Organisation for Economic Coopoeration and Development (OECD), and other relevant sectors such as oil and gas, mining, manufacturing, construction and marine sectors. *[See Appendix 15: Good practices in carbon footprint management]*

Part three: Recommendations

The below recommendations will be reviewed by the Ipieca Alternative Energy Task Force to agree on what Ipieca should be focusing on. Collaboration with stakeholders will be considered along the way.

RECOMMENDATIONS FOR SUPPLY CHAIN MANAGEMENT FOR WIND AND SOLAR

While some environmental and social risk management guidance within wind and solar generation exists, there are gaps which Ipieca has the expertise to fill.

1. Ipieca could consider developing guidance related to environmental risks such as:
   - Heavy metal toxicity, soil and groundwater acidification, habitat loss and fragmentation and impacts of deep-sea mining in the sourcing stage.
   - Sedimentation (relevant to offshore wind farms), chemical contamination, habitat loss, degradation and fragmentation in the manufacturing and construction stage.
   - Impact on bird migration patterns and electromagnetic field impacts on crustaceans in the operational stage.
   - Land use risks are widely covered by good practice guidance for the solar industry but there isn't any strong guidance for the wind industry.

2. Ipieca could consider developing guidance related to the environmental and social risks in the sourcing stage, particularly for companies sourcing materials in vulnerable developing countries. This could be done in collaboration with other stakeholders. Guidance could include the following:
   a. Engage with stakeholders to map minerals in developing resource-rich countries. (See World Bank Group, *The growing role of minerals and metals for a low carbon future*, 2017).
   b. Identify what metals and minerals are mostly used in companies' supply chains and conduct a risk assessment for each.
   c. Map those metals/minerals with most risks.
   d. Identify the most appropriate steps to minimise the risks.
   e. Lead initiatives to improve the conditions in the mapped regions and make mining more sustainable.

3. Ipieca could consider developing guidance on risks associated with the end-of-life stage.
   - Apart from the risks associated with solid waste and hazardous waste, good practice guidance does not cover the wider environmental and social risks (ecological damage and noise) within the supply chain in the end-of-life and decommissioning stage for either solar or wind technologies.

4. Ipieca could consider collaborating with stakeholders who are actively managing or providing guidance on the management of environmental and social risks within supply chains and on minimising the carbon footprint of solar and wind energy operations. *[See Appendix 16: Potential stakeholder collaborators]*

5. Ipieca could collaborate and learn from other sectors that are already active in managing their supply chains e.g., other than the renewable energy sector, the retail, food and processing and fashion industries are already active within this sphere. *[See Appendix 17: Potential renewables companies collaborators]*

6. Ipieca's *Environmental and social good practice for the energy transition: A compendium of Ipieca good practices* (2023) provides environmental and social guidance that could be incorporated into specific guidance for the supply chains of solar and wind energy technologies.

RECOMMENDATIONS FOR CARBON FOOTPRINT MANAGEMENT FOR WIND AND SOLAR

1. The most promising solutions to minimise the carbon emission in solar and wind projects are recycling, circularity and increasing the life span of wind farms.
   - Ipieca could benefit by collaborating and learning from the work being done by solar and wind companies with respect to recycling and share learnings/capture key good practices. *[See Appendix 18: Potential collaborators for carbon footprint management for wind and solar]*

2. Ipieca could develop good practice guidance on implementing land management techniques or nature-inclusive principles that ensures land used for solar and wind projects can effectively sequester carbon, thus avoiding the terrestrial portion of life cycle emissions.

3. Ipieca could draw on reports, policy and recommendations by governments, international organizations such as UNEP, UNFCCC, OECD and other relevant sectors, such as hydrocarbon, mining, manufacturing, construction, building and marine sectors to develop good practice guidance to minimise the carbon footprint of solar and wind projects.

4. Ipieca could conduct further research to identify the most relevant method for measuring the carbon footprint of renewable energy projects and initiatives and work to standardise the approach across the industry.

5. Ipieca could consider collaborating with stakeholders who are actively managing or providing guidance on minimising the carbon footprint of solar and wind energy operations. *[See Appendix 16: Potential stakeholder collaborators]*

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Appendices

Introduction

APPENDIX 1: ENVIRONMENTAL AND ECONOMIC BENEFITS OF SOLAR AND WIND ENERGY

Solar and wind energy together accounted for 88 per cent of all net renewable energy additions in 2021, increasing the capacity of renewable power by 257 GW (+9.1 per cent) (IRENA, 2022).

Several sources have so far highlighted the environmental and economic benefits of solar and wind energy. For instance, a study by the American Wind Energy Association (2020) concluded that a high scenario of 30 GW of operating offshore wind power by 2030 could support up to 83,000 jobs and deliver $25 billion annually in economic output in the United States. Another study by the IEA (2022) highlighted the potential of the solar PV industry to create 1300 manufacturing jobs for each gigawatt of production capacity, with module and cell manufacturing being the most job-intensive segments.

Whilst wind and solar technologies have far greater environmental benefits in comparison to fossil fuels in terms of climate change, particulates, ecotoxicity, human health, and eutrophication (UNEP, 2016) and have therefore become known as 'clean' fuels, these technologies can still have trade-offs throughout their life cycle if not properly managed.

Part one: Supply chain management for wind and solar

APPENDIX 2. SOURCING RISKS

In the following discussion, a clear distinction has been made between social and environmental risks in the section on "Sourcing," but not between solar and wind because of the huge overlap between both.

Social risks

Mancini and Nuss (2020) contend that societal and environmental factors can affect the availability of raw materials and present challenges for the transition to a low-carbon future. With a high dependence on mineral extraction and mining activities, environmental and social risks such as water stress, air pollution, soil and groundwater acidification, habitat loss and fragmentation and poor working conditions have been commonly reported in the literature (IEA, 2022; Bai et al., 2022; Sonter et al., 2020; Amnesty International, 2016).

Takeda et al. (2019) carried out a social LCA of solar and wind that revealed that currently, solar and wind energy can have impacts on people and societies. The study highlighted concerns for developing nations, where workers frequently experience poor working conditions as a part of the global supply chain. Additionally, a study by Huber & Steininger (2022) summarises the supply chain risks associated with the mining of minerals needed in the production of solar and wind energy technologies such as violations of human rights, financing of conflicts, lack of transparency, child labour, lack of safety standards and labour health issues. Among these minerals are also "conflict minerals", which refer to tantalum, tin, tungsten and gold (often referred to as 3TG metals), and their current mining is frequently linked to human rights violations and the financing of violent conflicts (Huber & Steininger, 2022; Responsible Minerals Initiative, n.d.). One of the most complex challenges to tackle these risks is that about 67 per cent of companies cannot distinguish which country their minerals originate from (Huber & Steininger, 2022; Küblböck & Grohs, 2017).

For instance, rare earth mining can have a high human cost in some places, such as the Democratic Republic of the Congo (DRC), with negative effects on the miners' quality of life with long working hours, human rights abuses, child labour and gender discrimination being reported by many studies (Heading et al., 2021). ActionAid (2018) reported that among the artisanal miners in the southern part of DRC, from where 20 per cent of the cobalt is currently exported, are children as young as seven, who scavenge for rocks containing cobalt in the discarded by-products of industrial mines. Children reportedly work between 10-12 hours a day in and around these cobalt mines, often carrying sacks of mineral ore weighing between 20-40 kg (Amnesty International, 2016). There are multiple case studies reported by ActionAid (2018) that take place as a result of mining for solar and wind technologies such as large-scale water and air pollution in China due to neodymium mining, gender discrimination in Zambia's copper mines, community and labour rights violations in Sierra Leone's iron mines and corruption in the iron ore mines of Liberia.

The table below summarises the application of several minerals in solar and wind energy technologies and their respective risks.

Table 2: Risks associated with solar and wind technology minerals (Huber & Steininger, 2022)

MINERAL	APPLICATION IN SOLAR AND WIND ENERGY	RISKS REPORTED
TIN (one of the conflict minerals)	• Semiconductor material in solar PV • Solder for solar PV and wind turbines • Lithium-ion batteries • Wind turbines • Amorphous silicon in solar PV • Tin oxide layer for thin film solar PV • Tin-based perovskite in solar PV	Human rights violations • Child labour • Poor working conditions • Revenue supporting warlords Poor governance, corruption or political instability • Linked to countries with poor governance • Reserves in fragile states • High political risk Toxicity • Heavy metal toxicity • Radiological Risks
RARE EARTH ELEMENTS	• NdFeB permanent magnets in direct-drive generators in wind turbines • Lithium-ion batteries • Generators	Human rights violations • Conflicts between locals and mining companies • Exploitation • Child Labour • Poor working conditions Poor governance, corruption or political instability • Reserves in fragile states • High political risk Toxicity • Significant cytotoxicity • Pulmonary embolisms • Can be fatal
COBALT	• NdFeB permanent magnets in direct-drive generators in wind turbines • Gearbox in wind turbines • Lithium-ion batteries	Human rights violations • Child labour • Poor working conditions Poor governance, corruption or political instability • Linked to countries with very poor governance • Reserves in fragile states • High political risk Toxicity • Hard metal lung disease • Asthma • Can be fatal

MINERAL	APPLICATION IN SOLAR AND WIND ENERGY	RISKS REPORTED
LITHIUM	• Wind turbines • Lithium-ion batteries	Human rights violations • Linked to violence Poor governance, corruption or political stability • Linked to corruption • Failing governance • Revenue used for personal enrichment • Reserves in fragile states Toxicity • Slurred speech • Confusion • Can be fatal

Environmental risks

One of the environmental effects of the growing adoption of alternative energy technologies is the increasing pressure put on mineral resources. Mineral demand, and therefore extraction, is expected to rise significantly. The production of several minerals, such as graphite, lithium, nickel, cobalt, and manganese, which are essential for solar and wind technologies, could increase by nearly 500 per cent by 2050. (Hund et al., 2020). IRENA (2021) lists cobalt, copper, nickel, lithium and rare earth metals (notably neodymium and dysprosium) as critical materials for the development of solar and wind technologies. A few studies also list aluminium, chromium, gallium, germanium, graphite, indium, iron and lead as critical materials, but most focus has been on the above-mentioned materials.

The percentage of overall demand increased dramatically over the following two decades, reaching over 40 per cent for copper and rare earth elements, 60-70 per cent for nickel and cobalt and almost 90 per cent for lithium under a scenario that achieves the goals of the Paris Agreement. An onshore wind farm consumes nine times more mineral resources than a gas-fired power station (IEA, 2022).

Mineral resource extraction and processing for solar and wind technologies can create several environmental and social risks that, if improperly handled, can disrupt supply and negatively impact local habitat, ecosystems and populations.

Several mining regions that provide the majority of raw materials required for the production of solar and wind energy are particularly susceptible to the effects of climate change. For example, 50 per cent of copper and lithium production is concentrated in areas such as Australia, Chile and China, which are subject to high water stress (IEA, 2022). The extraction of these materials requires significant quantities of pure water, the supply of which is becoming increasingly variable and vulnerable due to periods of extreme heat and droughts caused by climate change (ibid.).

Through direct processes (such as mineral extraction) and indirect ones (such as industries supporting mining operations and external stakeholders, including surrounding farmers, who gain access to biodiversity-rich areas as a result of mining), mining has an impact on biodiversity at multiple spatial scales (site, landscape, regional and global) (Sonter et al., 2018). Currently, 8 per cent of the global mining areas overlap with protected areas, 16 per cent with remaining wilderness regions and 7 per cent with key biodiversity areas (Sonter et al., 2020). Further overlap between these areas and mining is expected with the anticipated increased demand for solar and wind energy technologies and infrastructure.

Mining for solar and wind technologies can cause land use risks in natural habitats. One of the most documented risks is in forests. For example, land use change at mine sites, as well as downstream pollution and environmental harm, are some of mining's direct effects on forests. The construction of road, rail, and port infrastructure for the transportation and export of minerals, as well as the consequences associated with the influx of labour and other economic activity, like logging, can all have indirect and cumulative effects (Bradley, 2020). The World Bank's research found 3,300 large-scale mining operations in forests, 1,500 of which are operational and 1,800 of which are inactive or under construction. Signs of forest loss and degradation were found within 50 km, and in some cases within up to 100 km of the radius of the majority of the mines. According to the findings, mining may already impact up to one-third of the world's forests (Hund et al., 2020).

Rare-earth metals such as neodymium and dysprosium are used in the permanent magnets of some direct-drive wind turbines. Recent years have seen increasing concerns over the limited supply of rare-earth elements and the environmental harm caused by their mining and processing (UNEP, 2016). Due to their unique extraction and metallurgical processes, the increasing mining of rare-earth elements has significantly harmed nearby natural habitats. Acidification of the nearby soil and groundwater can result from mining effluent used in rare earth production (Bai et al., 2022) and can cause a decrease in soil nutrient availability, consequently affecting the soil's biological properties and plant performance (Yadav et al., 2020). The inferior quality of potable water resulting from acidification can deteriorate human health and affect the sustainable development of society (Karunanidhi et al., 2021). Heavy metal pollution and radioactive elements can result from mining solid waste, leading to food chain contamination, decreased soil fertility and health impacts, including hereditary diseases (Liu et al., 2022; Su et al., 2021; Wang et al., 2020).

With depleting reserves of rare-earth minerals and 90 per cent of their production dependent on China's mines, the concept of deep-sea mining has been gathering momentum (Moss, 2018). Deep-sea mining activities may result in the loss of species and long-term changes to the way marine communities behave (Van Dover, 2014). It is argued that plumes, which are clouds of silt that mining equipment scatters over the surrounding environment, might have a negative impact on marine life. Risers, which are used to transport hundreds of tonnes of ore up to surface boats, can discharge particles higher in the water column that might harm life in shallower seas and distribute over a wider region (Moss, 2018). Deep-sea mining can also potentially interrupt processes vital to the regulation of our climate, disrupting the delicate ecological balance of methane-rich hydrothermal vent zones, which support complex and diverse ocean ecosystems (Moss, 2018; Oregon State University, 2016).

APPENDIX 3: MANUFACTURING AND CONSTRUCTION RISKS

Manufacturing and construction of solar and wind technologies can create environmental and social risks that, if improperly handled, can disrupt supply and negatively impact local habitat, ecosystems and populations. For example, chemicals used to manufacture solar photovoltaic (PV) equipment can lead to a decrease in soil fertility and major health problems (Qi & Zhang, 2017). Construction noise and sedimentation impacting animal and plant growth can occur during the construction phase of deep water floating offshore wind turbines (Ferraz de Paula & Carmo, 2022).

Solar energy

The sizeable amount of land needed to construct a utility-scale solar power installation can interfere with the existing land uses. The clearing and grading of large tracts of land can result in soil compaction, erosion, and a change in drainage systems (Tajne, 2015). Numerous new solar power plants are being constructed on agricultural land, which destroys livelihoods and lowers local food production. As happened in Connecticut, where farmers who leased property found themselves in competition with clean energy, changes in land usage can cause conflicts in rural communities (Smith, 2018; Spiegel, 2017).

In addition, chemicals are used in the manufacturing of crystalline silicon solar cells for solar PV equipment, resulting in the generation of alkaline and organic effluent that contains fluorine and chromium (Qi & Zhang, 2017). If wastewater containing chromium is used to irrigate crops, it could result in decreased crop output and soil hardening (Gupta et al., 2010). Accumulation of chromium in the food chain can cause diseases like rhinitis, respiratory conditions, digestive system issues, and internal organ and skin corrosion (Smith, 2010). Chromium water consumption over an extended period of time can result in skin cancer. Long-term exposure to excessive fluoride levels results in major health problems, such as the development of tumours, dental fluorosis, osteoporosis, bone sclerosis and skeletal fluorosis (Guth et al., 2020).

Solar projects can cause a significant loss of natural habitat within the footprint area when combined with related infrastructure like access roads and powerlines. In order to build PV solar plants and the associated infrastructure, significant tracts of land must often be cleared of vegetation and surface graded. This may result in habitat loss, degradation and fragmentation, reducing the richness and density of species (Bennun et al., 2021; Visser et al., 2019). According to a study by Rehbein et al. (2020), only 17.4 per cent of large-scale (>10 MW) renewable energy installations, including hydropower, solar (PV), and wind, are located outside of significant conservation areas, such as key biodiversity areas (KBAs). Over 550 wind power initiatives and 200 solar (PV) developments, representing 9 per cent and 7 per cent of the total projects, respectively, are now operating within KBAs. Within KBAs, a further 162 wind and 152 solar projects are now in development. Given the importance of Southeast Asia's biodiversity to the world, the spread of renewable energy into new areas is a cause for concern.

Wind energy

Ferraz de Paula & Carmo (2022) list a range of environmental risks during the construction phase of deep water floating offshore wind turbines, notably:

- *Sedimentation:* Construction and decommissioning activities can result in particle suspension and dispersion, which in turn can lead to sedimentation, which can kill larvae and reduce coral fertilisation (Draget, 2014). Additionally, sedimentation can clog fish gills, causing respiratory issues and impaired feeding.
- *Construction noise:* Noise can alter the behaviour of dolphins, porpoises and seals. These animals frequently avoid the region under construction, which forces them to alter their habitat use.

The key issues in many wind farm construction projects concern acoustic disturbance and increased sediment dispersal linked to the engineering works required to anchor the turbines to the seabed. Offshore wind farms are usually built on monopiles or jacketed foundations, and the associated pile driving may generate appreciable levels of underwater noise, which can hurt or kill fish and other marine life (Henderson, 2019).
A study conducted by da Silva & Galvão (2022) to identify the sustainability challenges of onshore wind power generation in Northeast Brazil found several socio-ecological issues such as deforestation for the construction of wind farms, expropriation of subsistence arable land, generation of turbine noise, displacement of indigenous communities and extinction of cultural traditions.

APPENDIX 4: OPERATION RISKS

The operational phase poses risks such as obstacles to bird migration patterns, collision, habitat loss and battery system explosions (Ferraz de Paula & Carmo, 2022; Smallwood, 2007; Laranjeiro et al., 2018; Peng et al., 2020). Some of the materials contained in solar panels and turbine blades are hazardous, are not decomposed or recycled easily and could have negative impacts on the water, soil, air and human health during the end-of-life phase (Lewis Roca, 2021.; Ni et al., 2014).

Solar energy

Utility-scale solar projects can have major impacts on species and habitats. Biodiversity impacts can present risks to project developers, leading to project delays, disrupting project financing and threatening project sustainability credentials. Solar energy systems (including PV solar) have reported to have caused habitat loss, fragmentation and the degradation of surrounding habitats (The Biodiversity Consultancy, 2020).

Among solar energy systems, PV panel collectors such as heliostats could present a collision risk to bird and bats species, especially if the surfaces are vertically oriented and/or reflecting light (Bennun et al., 2021). According to research tracking fatalities over 13 years at 10 PV facilities in California and Nevada, on average 2.49 birds per MmW/year were expected to die due to collisions with equipment (Kosciuch et al., 2020).

Extrapolating from the Manufacturing and Construction section, meeting net-zero goals globally could require ~135 million acres (55 million ha) of land for solar energy production by 2050, assuming a global increase in development to about 18 TW installed capacity (IEA, 2022) and solar energy land use of 7.5 ac/MW (3.0 ha/MW) (Heath et al., 2022). Some estimates are even higher – 22 TW installed capacity by 2050, or about 165 million acres (67 million ha) (Fischer et al., 2022). The expansion of utility-scale solar development globally has increased the pressure on land resources for energy generation and other land uses (e.g., agriculture). Therefore, sustained development of solar energy will depend on finding renewable energy solutions that synergise the co-benefits of energy production, ecosystem services and other land uses. To address this growing issue, greater emphasis has been placed on solar development land-sharing strategies, such as agrivoltaics, that maximise the outputs of solar energy generation and multiple ecosystem services.

Wind energy

Some valid concerns raised with respect to wind turbines are the high noise levels produced by the rotor blades, visual impacts and deaths of birds and bats by the rotor blades. Moreover, it also reported that people who either live or work in close proximity to wind turbines experience or suffer from low quality of life, stress, hearing and sleep disturbance, annoyance and other effects. The noise produced by operational onshore wind turbines and their pictorial impact can be a key exasperation in human lives (Nazir et al., 2019).

Wind energy can also have significant impacts on wildlife. The main effects of wind energy on wildlife are collision, displacement and habitat changes. The majority of academic studies indicate that bats and birds are most vulnerable to the effects of wind turbines (Laranjeiro et al., 2018).

The combined impacts of magnetic influences (electromagnetic fields created by the electric cables), high levels of construction and operational noise and the height of towers, mean that wind farms can act as obstacles to bird migration patterns (Ferraz de Paula & Carmo, 2022). Additionally, collisions with wind farms, particularly at night, when animals have impaired vision, can lead to a high mortality rate for some species (Smallwood, 2007; Martin & Banks, 2023). In addition, these electromagnetic fields can have detrimental effects on crustaceans' sensitivity to electromagnetic fields and their ability to detect food, as well as generate needless avoidance or attraction reactions in vertebrate species that use geomagnetic navigation (Ferraz de Paula & Carmo, 2022).

A high-risk area during operation is created by the thermal and toxicological effects of battery system explosions, which release toxic gases such as CO, HF, SO_2, NO_2, NO, and HCl. These gases can cause severe health conditions, including respiratory diseases, fainting, dizziness and even cancer (Peng et al., 2020).

A well-documented risk is the impact of the construction and operation of wind turbines on fishing communities. Offshore wind plants have caused a diverse set of changes in the seafloor ecosystem. Such ecological impacts can alter biodiversity and species richness in the ocean. The major socio-economic effects for fisheries are the loss of fishing grounds, leading to effects on catch volume, gear conflicts (e.g., bottom trawl cannot be operated within offshore wind farms) and changes in travel time from the harbour to fishing grounds (Hoey et al., 2021). In Taiwan, where despite offshore wind power is an emerging favourable renewable energy, fishers have protested. Offshore development may affect fish resources, causing loss of catch and fishing income (Tseng & Kao, 2022). One of the major issues of concern is the impact of construction noise, which can permanently displace fish species from their breeding and feeding grounds (Methratta & Dardick, 2019). Such farms may result in disturbance to habitat on the sea floor from turbine construction, cable placement and barge anchorage (Tseng & Kao, 2022).

APPENDIX 5: END-OF-LIFE RISKS

The end of life of solar and wind technologies can create several environmental and social risks that, if improperly handled, can disrupt supply and negatively impact local habitat, ecosystems and populations.

Several studies have pointed out the potential impacts of decommissioning a wind or solar farm. The impacts are more profound in offshore windfarms than onshore windfarms and solar farms, which have greater ecological damage and noise impact. Even in the case of impacts on marine mammals, subtidal benthos, commercial fisheries, landscape and visual, offshore wind farms have a far greater impact. The possible decommissioning impacts of offshore wind farms associated with physical processes are changes to sediment movements, mobilisation of contaminants, fluidisation of seabed and smothering of habitats and increased turbidity (Hall et al., 2020). Offshore windfarms can also have impacts on benthic ecology in the form of habitat loss, the impact of noise on fish and marine mammals (the removal of structures and associated habitats and of areas for foraging, and the loss of prey species), and disturbance and displacement of birds, similar to the risks mentioned in the construction and operational stages of offshore windfarms (ibid).

Similarly, decommissioning of photovoltaic farms has been found to have negative impacts on the environment in the form of land use competition (mostly for agricultural land), degradation of vegetation, biodiversity loss, water pollution, soil contamination, thermal and air pollution and habitat fragmentation (Vrînceanu et al., 2019).

Given that an average solar panel has a lifetime of 30 years, large amounts of annual waste are anticipated by the early 2030s. These are equivalent to 4 per cent of installed PV panels in that year, with waste amounts by the 2050s (5.5-6 million tonnes) almost matching the mass contained in new installations (6.7 million tonnes) (IRENA, 2016). Finding a long-term solution for solar panels and turbine blades that have reached their end of life is one of the most urgent problems the renewable sector is facing. Some materials used in solar and wind energy are hazardous, do not decompose, or cannot be recycled. For instance, conventional solar panels include heavy metals and harmful chemicals such as polyvinyl fluoride, cadmium telluride, copper indium selenide, silicon tetrachloride, cadmium gallium (di)selenide and copper indium gallium (di)selenide (Lewis Roca, 2021) that are difficult to dispose of. Materials including bisphenol A, resin, and fibreglass that do not quickly disintegrate or recycle—if at all—are also found in wind turbines and blades (ibid).

A solar component that has come to its end of life—roughly 20 years for PV equipment—becomes solid waste (Qi & Zhang, 2017). Several components may be regarded as hazardous solid waste and may be harmful to the environment if disposed of improperly. Silicon, lead, cadmium, phosphorus and flame retardants will have a negative impact on water, soil, air, and human health if they are not properly treated or recycled (Ni et al., 2014). For instance, the Agbogbloshie dump in Ghana's capital Accra has become one of the world's largest destinations for used electronic goods. Due to the world's increasing demand for electronic equipment, the dump is only getting bigger. Respiratory problems, chronic nausea and debilitating headaches are common health impacts brought on by the hazardous working environment and toxic air pollution resulting from burning the waste (Yeung, 2019). The amount of worn-out solar panel material, much of it non-recyclable, together with more than 3 million tonnes per year of non-recyclable polymers from worn-out wind turbine blades will make up double the tonnage of all existing global plastic trash by 2050, according to current plans (Mills, 2020).

APPENDIX 6: GUIDANCE FOR SUPPLY CHAIN MANAGEMENT

Useful resources

Due diligence

- *Due Diligence Guidance for responsible supply chains of minerals from conflict-affected and high-risk areas* (OECD, 2016)
- *Due Diligence Guidance for Meaningful Stakeholder Engagement in the Extractive Sector* (OECD, 2017)
- *Cobalt Refiner Supply Chain Due Diligence Standard* (RCI & RMI, 2022)
- *Joint Due Diligence Standard for Copper, Lead, Molybdenum, Nickel and Zinc* (The Copper Mark, 2022)
- *Responsible Minerals Assurance Process: Global Responsible Sourcing Due Diligence Standard for Mineral Supply Chains All Minerals* (RMI, 2022)
- *IRMA Standard for Responsible Mining IRMA-STD-001* (IRMA, 2018)
- *OECD Due Diligence Guidance for Responsible Business Conduct* (OECD, 2018)
- *Responsible business conduct for institutional investors: Key considerations for due diligence under the OECD Guidelines for Multinational Enterprises* (OECD, 2017)
- *Human rights due diligence guidance* (Ipieca, 2021)

The following resources may also be useful for companies who wish to manage their supply chains within the solar and wind industry:

- *The Due Diligence for Meaningful Stakeholder Engagement in the Extractive Sector* (OECD, 2017) covers topics such as stakeholder engagement, responsible business conduct and due diligence framework with a focus on the extractive sector.

- *OECD Due Diligence Guidance for Responsible Business Conduct* (OECD, 2018) helps businesses (enterprises) to understand and implement due diligence for Responsible Business Conduct (RBC) as foreseen in the OECD Guidelines for Multinational Enterprises (MNEs) (due diligence).
- *Responsible business conduct for institutional investors: Key considerations for due diligence under the OECD Guidelines for Multinational Enterprises* (OECD, 2017) provides a resource for institutional investors and their stakeholders to help investors implement the recommendations of the OECD Guidelines along the investment value chain.
- *Responsible Minerals Assurance Process: Environmental, Social & Governance (ESG Standard) for Mineral Supply Chains* (RMI, 2021) issues an ESG Standard that sets forth criteria for determining conformance with the RMI program requirements for environmental, social, health & safety, and governance at mineral processing companies.
- *Responsible Minerals Assurance Process: Global Responsible Sourcing Due Diligence Standard for Mineral Supply Chains all Minerals* (RMI, 2022) sets forth the criteria for determining conformance with RMI program requirements for responsible minerals supply chain due diligence applicable to all minerals and metal products.

Responsible sourcing

- *Meeting the milestones in the responsible sourcing roadmap: Good Practice guidelines for renewable energy sector* (Farooki et al., 2021)
- *Cobalt Refiner Supply Chain Due Diligence Standard* (RCI & RMI, 2022)
- *Joint Due Diligence Standard for Copper, Lead, Molybdenum, Nickel and Zinc* (The Copper Mark, 2022)
- *Responsible Minerals Assurance Process: Environmental, Social and Governance (ESG) Standard for Mineral Supply Chains* (RMI, 2021)
- *Responsible Minerals Assurance Process: Global Responsible Sourcing Due Diligence Standard for Mineral Supply Chains All Minerals* (RMI, 2022)
- *Towards Sustainable Mining (TSM) Protocols* (TSM Initiative, 2018)

Recycling

- *End-of-life management: Solar Photovoltaic Panels* (IRENA & IEA, 2016)
- *Guidelines for assessing end-of-life management options for renewable and battery energy storage technologies* (EPRI, 2021)
- *Accelerating wind turbine blade circularity* (Wind Europe et al., 2020)
- *Solar Photovoltaic Module Recycling: A Survey of US Policies and Initiatives* (NREL, 2021a)
- *A Circular Economy for Solar Photovoltaic System Materials: Drivers, Barriers, Enablers, and US Policy Considerations* (NREL, 2021b)
- *Best practices at the End of the Photovoltaic System Performance Period* (NREL, 2021c)

MEETING THE MILESTONES IN THE RESPONSIBLE SOURCING ROADMAP: GOOD PRACTICE GUIDELINES FOR THE RENEWABLE ENERGY SECTOR

Developer	European Union (EU) (Farooki et al., 2021)
Year published	2021
Supply chain stage(s) covered	Sourcing
Risks addressed	Human rights, biodiversity
Description	The EU's guidelines focus on good practices for the responsible sourcing of minerals for renewable energy (Farooki et al., 2021). The document outlines key practices for the renewable energy sector to promote peer learning and increase the uptake of responsible sourcing practices. Four good practice recommendations are detailed in the document along with case studies that demonstrate their application. The first and fourth good practice principles are especially pertinent to supply chain management: • Coherent sustainability approach for an extractive company: using the case of Antofagasta Minerals (Chile) mining company, it outlines the steps in creating such a strategy, from drafting a vision to creating the appropriate management structure and tools to support its sustainable implementation. • Full LCA business model: it presents considerations for the LCA system design and decommissioning cost of solar panel farms. • Shared supplier assessment scheme and database: describes an example from the chemical sector and the efficiency gained from the economies of scale. The case presentations consider the crucial steps at the beginning, particularly the communication and engagement with suppliers. • Consultative approach for designing a national mining policy: the main aspects of this policy comprise communicating and engaging with stakeholders to ensure participation, particularly from under-represented communities.
URL	https://re-sourcing.eu/content/uploads/2022/11/d5.2_res_guidance-document_final.pdf

DUE DILIGENCE GUIDANCE FOR RESPONSIBLE SUPPLY CHAINS OF MINERALS FROM CONFLICT-AFFECTED AND HIGH-RISK AREAS

Developer	Organisation for Economic Co-operation and Development (OECD)
Year published	2016
Supply chain stage(s) covered	Sourcing
Risks addressed	Human rights

Description	OECD's guidance is a cooperative, multi-stakeholder initiative with government support that focuses on ethical supply chain management of minerals from conflict zones. Its goal is to support businesses in upholding human rights and avoiding conflict through their mineral procurement methods. With a view to enabling nations to profit from their mineral resources and preventing the extraction and trade of minerals from becoming a source of conflict, human rights abuses, and insecurity, the guidance also aims to cultivate transparent mineral supply chains and sustainable corporate engagement in the mineral sector. Like the RMI report, although the guidance is not specifically based on the supply chains of the renewable energy sector, the guidance is relevant owing to the renewable energy sector's high dependence on raw materials which are sourced from places subject to social and environmental risks.
URL	https://www.oecd.org/corporate/mne/mining.htm

DUE DILIGENCE GUIDANCE FOR MEANINGFUL STAKEHOLDER ENGAGEMENT IN THE EXTRACTIVE SECTOR

Developer	Organisation for Economic Co-operation and Development (OECD)
Year published	2017a
Supply chain stage(s) covered	Sourcing
Risks addressed	Stakeholder Engagement, Responsible Business Conduct
Description	The aim of this document is to offer practical guidance for the extractive sector in line with the provisions of the OECD Guidelines on due diligence for stakeholder engagement. Extractive sector enterprises are considered to include enterprises conducting exploration, development, extraction, processing, transport, and/or storage of oil, gas and minerals. The guidance provides a due diligence framework for enterprises operating in the extractive sector to identify and manage risks with regard to stakeholder engagement activities to ensure they play a role in avoiding and addressing adverse impacts as defined in the OECD Guidelines. This Guidance is divided into five sections including: 1. A due diligence framework for meaningful stakeholder engagement; 2. Recommendations for corporate planning or to upper management on the strategic positioning of stakeholder engagement; 3. Recommendations to on-the-ground personnel; 4. An annex including a monitoring and evaluation framework for overseeing stakeholder engagement activities; 5. Four thematic annexes including thematic guidance on engaging with indigenous peoples, women, workers and artisanal and small-scale miners.
URL	https://www.oecd.org/publications/oecd-due-diligence-guidance-for-meaningful-stakeholder-engagement-in-the-extractive-sector-9789264252462-en.htm

COBALT REFINER SUPPLY CHAIN DUE DILIGENCE STANDARD

Developer	Responsible Cobalt Initiative (RCI), Responsible Minerals Initiative (RMI)
Year published	2022
Supply chain stage(s) covered	Sourcing
Risks addressed	Responsible Sourcing, Risks associated with Cobalt (Human Rights, Armed Conflicts, Political Instability, Corruption, Insurgencies)
Description	This Standard encourages companies to source responsibly from Conflict-Affected and High-Risk Areas (CAHRA), and where relevant, from artisanal and small-scale mineral producers. Procurement responsibilities include due diligence and risk management but may further include engagement with stakeholders in the supply chain to drive positive impact for the local communities that are beyond the actions required under this Standard. Companies are encouraged to engage with their supply chain actors to identify, assess and mitigate risks associated with CAHRAs. The Standard follows the five-step framework for risk-based due diligence from the Chinese Due Diligence Guidelines for Minerals Supply Chains (Chinese Guidelines) and the OECD Due Diligence Guidance for Responsible Mineral Supply Chains from Conflict-Affected and High-Risk Areas, Edition 3 (OECD Guidance). This Standard includes additional requirements related to effective engagement with local communities (Step 6: Community Participation) for companies located in CAHRAs. This Standard also includes recommendations for managing additional Environmental, Social and Governance issues, beyond the OECD Guidance. **Step 1:** Establish Strong Company Management Systems **Step 2:** Identify and Assess Risks in the Supply Chain **Step 3:** Design and Implement a Strategy to Respond to Identified Risks **Step 4:** Independent Third-Party Assessment of Company Due Diligence Practices **Step 5:** Report Annually on Supply Chain Due Diligence **Step 6:** Community Participation
URL	https://www.responsiblemineralsinitiative.org/media/docs/standards/Cobalt%20Refiner%20Supply%20Chain%20Due%20Diligence%20Standard%20(Version%202.0)_EN.pdf

JOINT DUE DILIGENCE STANDARD FOR COPPER, LEAD, MOLYBDENUM, NICKEL AND ZINC

Developer	The Copper Mark
Year published	2022
Supply chain stage(s) covered	Sourcing
Risks addressed	Social Risks

Description	The Standard takes into account the risk profile of copper, lead, molybdenum, nickel and zinc (the principal covered metals) supply chains and is designed to enable effective due diligence for producers and/or traders of these metals. It intends to build on existing standards and looks to provide flexibility for multi-metal producers to include materials intended for the production of metal products other than principal covered metals at their site(s) as needed. The Standard was developed to: 1. Enable the implementation of the OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas (OECD Guidance) for producers and/or traders of copper, lead, molybdenum, nickel and zinc. 2. Enable compliance with market entry requirements, specifically the responsible sourcing policy requirement for Brand Compliance, Track A, and Recognised Alignment-Assessed Standard Track, defined by the London Metal Exchange (LME) for LME Brands. 3. Enable conformance with criterion 31: Responsible Supply Chains, *The Copper Mark Criteria*. The Copper Mark uses the criteria defined by the Risk Readiness Assessment (RRA) developed and maintained by the RMI. 4. Encourage companies to source responsibly from Conflict-Affected and High-Risk Areas (CAHRA) and to not categorically exclude suppliers. 5. Complement other third-Party assurance programmes and allow for the recognition of other standards that have been found to be OECD-aligned. 6. Provide flexibility for multi-metal producers to include materials intended for the production of metal products other than of principal covered metals at their site(s) (Annex I: Guidance on Companies Producing Multiple Metals available on Page 47 of the document)
URL	https://coppermark.org/standards/due-diligence/

MINING LOCAL PROCUREMENT REPORTING MECHANISM

Developer	Deutsche Gasellschaft für Internationale Zusammenarbeit (GIZ) GmBH, Mining Shared Value – an initiative of Enginners Without Borders Canada
Year published	2017
Supply chain stage(s) covered	Sourcing
Risks addressed	Corruption, Child Labour, Forced Labour, Human Rights Abuses
Description	The Mining Local Procurement Reporting Mechanism (LPRM) is a set of disclosures on local procurement that are to be reported by organisations who report on mine sites. The LPRM addresses the gaps in current reporting frameworks and sustainability systems, and to help standardise the way the sector and host countries talk about these issues. It facilitates comprehensive reporting on local procurement spending at the site level, as well as practical details on mining company procurement processes and programmes that support better-informed stakeholders.

	The objectives of increasing and standardising the way in which the mining industry reports on local procurement are to: 1. Improve internal management in mining companies to create more benefits for host countries and to strengthen their social licence to operate. 2. Empower suppliers, host governments, and other stakeholders with practical information that will help them collaborate with mine sites. 3. Increase transparency in the procurement process to deter problematic practices, such as corruption.
URL	https://miningsharedvalue.org/mininglprm#:~:text=The%20Mining%20Local%20Procurement%20Reporting%20Mechanism%20(LPRM)%20is%20a%20set,and%20talk%20about%20local%20procurement.

PRACTICAL ACTIONS FOR COMPANIES TO IDENTIFY AND ADDRESS THE WORST FORMS OF CHILD LABOUR IN MINERAL SUPPLY CHAINS

Developer	Organisation for Economic Co-operation and Development (OECD)
Year published	2017b
Supply chain stage(s) covered	Sourcing
Risks addressed	Child Labour
Description	This report is for use by companies to help them identify, mitigate and account for the risks of child labour in their mineral supply chains. It has been developed to build on the due diligence framework of the OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Areas. The Practical Actions do not represent new or additional recommendations from the OECD but aim to explain in simple terms the recommendations set out in the OECD Due Diligence Guidance to identify, assess and address the risks of the worst forms of child labour in the minerals supply chain. Companies should refer to the full text of the OECD Due Diligence for detailed due diligence recommendations with regards to sourcing minerals from conflict-affected and high-risk areas.
URL	https://mneguidelines.oecd.org/Practical-actions-for-worst-forms-of-child-labour-mining-sector.pdf

RESPONSIBLE MINERALS ASSURANCE PROCESS: ENVIRONMENTAL, SOCIAL & GOVERNANCE (ESG) STANDARD FOR MINERAL SUPPLY CHAINS

Developer	Responsible Minerals Initiative (RMI)
Year published	2021
Supply chain stage(s) covered	Sourcing
Risks addressed	ESG Standard
Description	The Responsible Minerals Initiative (RMI) encourages the responsible sourcing of minerals globally. To incentivize and improve on-site practices in the mineral value chain, the RMI issues this voluntary Environmental, Social and Governance (ESG) standard for mineral supply chains. This standard sets forth the criteria for determining conformance with the RMI program requirements for environmental, social, health & safety, and governance at mineral processing companies. The standard was benchmarked against and is consistent with the RMI's Risk Readiness Assessment and the RBA's Validated Assessment Process (VAP), and nineteen other existing international credible ESG standards (twelve of which are specific to and/or sponsored by metals processing industries).
URL	https://www.responsiblemineralsinitiative.org/media/docs/standards/RMI_RMAP%20ESG%20Standard%20for%20Mineral%20Supply%20Chains_June32021_FINAL.pdf

RESPONSIBLE MINERALS ASSURANCE PROCESS: TIN AND TANTALUM STANDARD

Developer	Responsible Minerals Initiative (RMI)
Year published	2018
Supply chain stage(s) covered	Sourcing
Risks addressed	Conflict, Human rights abuses, insecurity
Description	The Responsible Minerals Assurance Process (formerly the Conflict Free Smelter Program (CFSP)) was established to cultivate transparent mineral supply chains and sustainable corporate engagement in the mineral sector with a view to prevent the extraction and trade of minerals from becoming a source of conflict, human rights abuses, and insecurity. This standard was developed as a specific, practical framework to consistently audit the operations and practices of tin and tantalum smelters, the point at which mineral is converted into a generic metallic powder, product or compound. It follows guidance provided by the final report of the UN Group of Experts to the Security Council on 15th November 2010, and by the Organization of Economic Co-operation and Development Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas Third Edition (OECD Guidance)
URL	https://www.responsiblemineralsinitiative.org/media/docs/standards/Responsible%20Minerals%20Assurance%20Process_Standard_SnTa_EN.pdf

RESPONSIBLE MINERALS ASSURANCE PROCESS: GLOBAL RESPONSIBLE SOURCING DUE DILIGENCE STANDARD FOR MINERAL SUPPLY CHAINS ALL MINERALS

Developer	Responsible Minerals Initiative (RMI)
Year published	2022
Supply chain stage(s) covered	Sourcing
Risks addressed	Due Diligence
Description	The RMI encourages the responsible sourcing of minerals from Conflict-Affected and High-Risk Areas (CAHRAs), and, where relevant, artisanal and small-scale mining (ASM) producers. This document sets forth the criteria for determining conformance with RMI program requirements for responsible minerals supply chain due diligence applicable to all minerals and metal products as specified in Chapter II of this document. The criteria in this document establish operational and procedural standards for companies. The standard is used by an RMI-approved audit firm and their approved individual auditors to assess whether a company has implemented OECD aligned supply chain due diligence adapted to the circumstances and type of its operations, reflecting its position in the supply chain.
URL	https://www.responsiblemineralsinitiative.org/media/docs/standards/ResponsibleMineralsAssuranceProcess_Standard_AllMinerals_EN_121422.pdf

TOWARDS SUSTAINABLE MINING (TSM) PROTOCOLS

Developer	TSM Initiative
Year published	2018
Supply chain stage(s) covered	Sourcing
Risks addressed	Biodiversity risks, Climate Change, Child Labour, Forced Labour, Water Risks etc.
Description	TSM is implemented through a suite of protocols that mining companies measure and publicly report their performance against in annual TSM Progress Reports. Each protocol is made up of a set of indicators that are designed to measure the quality and comprehensiveness of facility-level management systems and are intended to provide the public with an overview of the industry's performance in key environmental and social areas. Each participating organisation has the ability to make minor adjustments to suit the particular needs of their jurisdiction. List of protocols: • Biodiversity Conservation Management • Climate Change • Crisis Management and Communications Planning

	• Exploration • Indigenous and Community Relationships • Mine Closure • Preventing Child and Forced Labour • Safety and health • Tailings Management • Water Stewardship The TSM Responsible sourcing Supplement was developed to support companies that are implementing the TSM standard alongside the following additional standards: • International Council on Mining and Metals' (ICMM) Mining Principles (MPs) • World Gold Council (WGC) Responsible Gold Mining Principles (RGMPs) • Responsible Minerals Initiative (RMI) Risk Readiness Assessment (RRA) including the International Copper Alliance (ICA) Copper Mark (CM)
URL	https://tsminitiative.com/protocols-frameworks#responsible-sourcing-alignment-supplement

GRI 408: CHILD LABOUR 2016

Developer	Global Reporting Initiative (GRI)
Year published	2016
Supply chain stage(s) covered	Sourcing
Risks addressed	Child Labour
Description	GRI 408: Child Labour 2016 contains disclosures for organisations to report information about their impacts related to child labour, and how they manage these impacts. The Standard is structured as follows: • Section 1 contains a requirement, which provides information about how the organisation managed its impacts related to child labour. • Section 2 contains one disclosure, which provides information about the organisation's impacts related to child labour. This Standard addresses the topic of child labour. Due diligence is expected of an organisation in order to prevent the use of child labour in its activities. It is also expected to avoid contributing to, or becoming complicit in, the use of child labour through its relationships with others (e.g., suppliers, and clients). These concepts are covered in key instruments of the ILO, the OECD, and the UN. The Standard is part of the GRI Sustainability Reporting Standards (GRI Standards). The GRI Standards enable an organisation to report information about its most significant impacts on the economy, environment and people, including impacts on their human rights, and how it manages these impacts.
URL	https://globalreporting.org/pdf.ashx?id=12622&page=1

GRI 409: FORCED OR COMPULSORY LABOUR 2016

Developer	Global Reporting Initiative (GRI)
Year published	2016
Supply chain stage(s) covered	Sourcing
Risks addressed	Forced Labour
Description	GRI 409: Forced or Compulsory Labour 2016 contains disclosures for organisations to report about their impacts related to forced or compulsory labour, and how they manage these impacts. The Standard is structured as follows: • Section 1 contains a requirement, which provides information about how the organisation manages its impacts related to forced or compulsory labour. • Section 2 contains one disclosure, which provides information about the organisation's impacts related to forced or compulsory labour. This Standard addresses the topic of forced or compulsory labour. Due diligence is expected of an organisation in order to prevent the use of child labour in its activities. It is also expected to avoid contributing to, or becoming complicit in, the use of child labour through its relationships with others (e.g., suppliers, and clients). These concepts are covered in key instruments of the ILO, the OECD, and the UN.
	• The Standard is part of the GRI Sustainability Reporting Standards (GRI Standards). The GRI Standards enable an organisation to report information about its most significant impacts on the economy, environment, and people, including impacts on their human rights, and how it manages these impacts.
URL	https://globalreporting.org/pdf.ashx?id=12633&page=8

IRMA STANDARD FOR RESPONSIBLE MINING IRMA-STD-001

Developer	Initiative for Responsible Mining Assurance (IRMA)
Year published	2018
Supply chain stage(s) covered	Sourcing
Risks addressed	Range of social and environmental risks as listed below
Description	The IRMA Standard for Responsible Mining (the IRMA Standard) is designed to support the achievement of four overarching principles. Additionally, each chapter of the IRMA Standard has an objective that meets one or more of these principles.

	• Principle 1 – Business Integrity - Chapter 1.1 – Legal Compliance - Chapter 1.2 – Community and Stakeholder Engagement - Chapter 1.3 – Human Rights Due Diligence - Chapter 1.4 - Complaints and Grievance Mechanism and Access to Remedy - Chapter 1.5 – Revenue and Payment Transparency • Principle 2 – Planning and Managing - Chapter 2.1 – Environmental and Social Impact Assessment and Management - Chapter 2.2 – Free, Prior and Informed Consent (FPIC) - Chapter 2.3 – Obtaining Community Support and Delivery Benefits - Chapter 2.4 – Resettlement - Chapter 2.5 – Emergency Preparedness and Response - Chapter 2.6 – Planning and Financing Reclamation and Closure • Principle 3 – Social Responsibility - Chapter 3.1 – Fair Labour and Terms of Work - Chapter 3.2 – Occupational health and Safety - Chapter 3.3 – Community Health and Safety - Chapter 3.4 – Mining and Conflict-Affected or High-Risk Areas - Chapter 3.5 – Security Arrangements - Chapter 3.6 – Artisanal and Small-Scale Mining - Chapter 3.7 – Cultural Heritage • Principle 4 – Environmental Responsibility - Chapter 4.1 – Waste and Materials Management - Chapter 4.2 – Water Management - Chapter 4.3 – Air Quality - Chapter 4.4 – Noise and Vibration - Chapter 4.5 – Greenhouse Gas Emissions - Chapter 4.6 – Biodiversity, Ecosystem Services and Protected Areas - Chapter 4.7 – Cyanide - Chapter 4.8 – Mercury Management
URL	https://responsiblemining.net/wp-content/uploads/2018/07/IRMA_STANDARD_v.1.0_FINAL_2018-1.pdf

ICMM MINING PRINCIPLES

Developer	International Council on Mining and Metals
Year published	2022
Supply chain stage(s) covered	Sourcing
Risks addressed	Range of social and environmental risks as listed below

Description	ICMM's Mining Principles respond to evolving societal expectations of the mining and metals industry. ICMM's Mining Principles define the good practice environmental, social and governance requirements of company members through a comprehensive set of 39 Performance Expectations and eight related position statements on a number of critical industry challenges. Implementation of the Ming Principles will support progress towards the global targets of the UN Sustainable Development Goals and the Paris Agreement on climate change. Incorporating robust site-level validation of performance expectations and credible assurance of corporate sustainability reports, ICMM's Mining Principles seek to maximise the industry's benefits to host communities, while minimising negative impacts to effectively manage issues of concern to society. Performance Expectations: Defining good practice environmental, social and governance requirements for the mining and metals industry: 1. Ethical Business 2. Decision-Making 3. Human Rights 4. Risk Management 5. Health and Safety 6. Environmental Performance 7. Conservation of Biodiversity 8. Responsible Production 9. Social Performance 10. Stakeholder Engagement
URL	https://www.icmm.com/website/publications/pdfs/mining-principles/mining-principles.pdf?cb=10319

SOLAR INDUSTRY COMMITMENT TO ENVIRONMENTAL & SOCIAL RESPONSIBILITY

Developer	Solar Energy Industries Association (SEIA)
Year published	2021
Supply chain stage(s) covered	Sourcing, construction, operation
Risks addressed	Human rights (forced labour), environment, health
Description	The Solar commitment was launched to help tackle the associated social and environmental risks of the solar energy industry. Created through a multi-stakeholder approach, it is an industry code of conduct that establishes expectations and common practices for matters relating to management systems for the environment, health and safety. Its guiding principles include increased credibility, increased effectiveness and innovation, increased industry impact, proven leadership in sustainability and a persistent commitment to advancing corporate social responsibility (SEIA, 2021a).

	Based on the commitment, the US government has highlighted forced labour as a risk for the solar supply chain. To address this concern and build upon the industry's current corporate social responsibility platform, *a Solar supply chain traceability protocol 1.0* has also been developed. The protocol is a collection of suggested policies and practises created to identify the origin of a product's raw materials and track their flow along the supply chain (SEIA, 2021b).
URL	https://www.seia.org/sites/default/files/2021-04/SEIA-Solar-Commitment-Participant-Handbook-2021.pdf https://www.seia.org/sites/default/files/2021-04/SEIA-Supply-Chain-Traceability-Protocol-v1.0-April2021.pdf

ENVIRONMENTAL AND SOCIAL GOOD PRACTICE FOR THE ENERGY TRANSITION: A COMPENDIUM OF IPIECA GOOD PRACTICES

Developer	Ipieca
Year published	2023
Supply chain stage(s) covered	Manufacturing, construction, operation
Risks addressed	Biodiversity risks, Water management, Labour rights, health, Human rights

Description	Through Ipieca, the oil and gas industry has developed a range of good practice guides to aid responsible environmental and social management. These guides have relevance to other sectors and energy projects. This compendium highlights Ipieca environmental and social management practices that carry cross-learnings for energy producers beyond oil and gas. Applicability varies depending on a number of factors, including physical footprint, timescales and locations.
	
	This compendium is intended for the use of Ipieca members and beyond. It communicates to external stakeholders and other associations, the potential of the oil and gas industry to contribute useful practices and learnings for the alternative energy sector.
	
	A few highly applicable Ipieca good practices to alternative energy are given below:
	• Sustainability
	  - Supply chain library of questions and resources (2020)
	• Environment
	  - A guide to developing biodiversity action plans (2022)
	  - Water management framework (2021)
	  - Biodiversity and ecosystem services fundamentals (2016)
	  - A cross-sector guide for implementing the mitigation hierarchy (2015)
	  - Good practices for the collection of biodiversity baseline data (2015)
	  - A cross-sector biodiversity initiative timeline tool (2013)
	  - Alien invasive species and the oil and gas industry (2010)
	  - Managing Biodiversity & Ecosystem Services (BES) issues along the asset life cycle in any environment: 10 tips for success in the oil and gas industry (2010)

	• Social - Local content measurement and reporting (2023) - Online labour rights training (2023) - Labour rights risk identification in the supply chain (2021) - Human rights due diligence guidance (2021) - Community development agreement (2019) - Responsible recruitment and employment (2019) - Labour rights assessment (2019) - Labour rights assessment toolkit (2019) - Key steps for carrying out an on-site labour rights assessment (2019) - Worker grievance mechanisms (2019) - Managing fatigue in the workplace (2019) - Health management in the oil and gas industry (2019) - Making the business case for Corporate Social Responsibility (2018) - Creating successful, sustainable social investment (2nd edition) (2017) - Redefining key components of social investment: Practitioner note 1 (2017) - Monitoring and evaluation of social investment: Practitioner note 2 (2017) - Health impact assessment (2016) - Infectious disease outbreak management (2016) - Community grievance mechanisms in the oil and gas industry (2015) - Integrating human rights into environmental, social and health impact assessments (2013) - Voluntary Principles on Security and Human Rights: Implementation guidance tools (2012)
URL	https://www.ipieca.org/resources/awareness-briefing/environmental-and-social-good-practice-for-the-energy-transition-a-compendium-of-ipieca-good-practices/

OFFSHORE IMPACTS TO FISHERIES: PRACTITIONER GUIDANCE FOR SOCIAL BASELINES

Developer	Ipieca
Year published	2023
Supply chain stage(s) covered	Manufacturing, construction, operation
Risks addressed	Impact on fishing communities
Description	Ipieca recognises that there is an opportunity to support practitioners to develop robust social baselines for offshore projects. This guidance seeks to support practitioners to make informed decisions when it comes to designing and implementing social baseline data collection processes. Purpose of this Guidance: It is not intended that this guidance explain what a social baseline is or why it is important to properly characterize impacts, but rather it is to be used to enhance consistency in social baselines. More specifically, to support practitioners in selecting the right data collection tools at the appropriate stage in the project life cycle to inform better outcomes for both communities and proponents

	Accordingly, this guidance is designed to help practitioners develop social baselines that: • Suitably characterise impacts to fisheries and associated stakeholders • Can be scaled to suit a variety of different offshore contexts and projects • Will stand up to institutional scrutiny • Reduce delays associated with the collection of incorrect data • Support efforts to avoid and/or minimise impacts on fisheries and associated communities
URL	https://www.ipieca.org/resources/offshore-impacts-to-fisheries-practitioner-guidance-for-social-baselines

MITIGATING BIODIVERSITY IMPACTS ASSOCIATED WITH SOLAR AND WIND ENERGY DEVELOPMENT: GUIDELINES FOR PROJECT DEVELOPERS

Developer	IUCN, The Biodiversity Consultancy, BirdLife International, Fauna & Flora International, The Nature Conservancy, Wildlife Conservation Society, Électricité de France (EDF), Energias de Portugal (EDP), Shell
Year published	2021
Supply chain stage(s) covered	Manufacturing, construction, operation, end of life
Risks addressed	Biodiversity (habitat loss and fragmentation, pressures on local water resources, impact on areas of conservation significance, collision risks and high noise)
Description	The guidelines aim to manage risks and enhance overall outcomes in relation to biodiversity and ecosystem services to give practical support for solar and wind energy developments. The recommendations span the whole project life cycle, from early planning through to decommissioning and repowering, and are industry focused. They use the mitigation hierarchy as a framework for planning and implementation which highlights crucial issues associated with the impact of solar and wind energy expansion on biodiversity such as habitat loss and fragmentation, pressures on local water resources, impact on areas of conservation significance, collision risks and high noise during construction (Bennun et al., 2021).
URL	https://portals.iucn.org/library/node/49283

THE LIFE CYCLE QUALITY: BEST QUALITY GUIDELINES (VERSION 1.0)

Developer	SolarPower Europe
Year published	2021
Supply chain stage(s) covered	Construction, operation, maintenance
Risks addressed	Health, safety, security & environment, due diligence, quality management

Description	The best practice guidelines are a series of recommendations for engineering, procurement and construction, operation and maintenance and asset management. The recommendations define the relevant stakeholders and advise how to involve them at each step of a project. They combine the four major pillars of lifetime project management: • Risk analysis: risk identification, risk assessment, risk prevention and mitigation, and risk plan communication and implementation • Health, safety, security & environment (HSSE): rules and regulations in place to guarantee workplace security, environmental preservation, and worker and customer health and safety. They were created in compliance with national and European rules and regulations, and they are applicable to both employees and visitors • Due diligence: consists of four sub-areas – legal, technical, financial and political • Quality management: a commitment to customers in the market or as fitness for the intended use (how well the product performs its intended function) The guidelines also highlight the need for solar projects to comply with national laws and globally recognised standards to protect the environment and maintain a safe and healthy workplace.
URL	https://www.seia.org/sites/default/files/2021-04/SEIA-Supply-Chain-Traceability-Protocol-v1.0-April2021.pdf

GUIDANCE – GOOD PRACTICE DURING WIND FARM CONSTRUCTION

Developer	NatureScot
Year published	2019
Supply chain stage(s) covered	Construction, Operation
Risks addressed	Pollution prevention, Protection of the environment and natural resources, hydrology and archaeology related issues and the adoption of biosecurity protocols, including the control of invasive and non-native species
Description	Considerable experience has been gained from the construction and operation of wind farms across Scotland with an installed capacity totalling over 7500 Megawatts. The purpose of this guidance is to share that experience amongst the industry, planning authorities, key agencies and those more broadly involved in the planning and development of wind farms. It is focused on pollution prevention, protection of the environment and natural resources, hydrology and archaeology related issues and the adoption of biosecurity protocols, including the control of invasive and non-native species. The guidance is aimed at: • Wind farm developers • Construction companies and contractors working on wind farm sites • Consultants and advisers supporting the wind farm industry • Planning officers working on wind farm applications • Statutory consultees and Key Agencies • Clerks of Works

URL	https://www.nature.scot/doc/guidance-good-practice-during-wind-farm-construction

LARGE-SCALE SOLAR SITING: ENCOURAGING ECOSYSTEM ENHANCEMENT AND CONSERVATION WHILE PRODUCING MUCH NEEDED ZERO-CARBON ELECTRICITY

Developer	Gahl & Norris (Solar and Storage Industries Institute, SSII)
Year published	2022
Supply chain stage(s) covered	Construction, Operation
Risks addressed	Biodiversity risks, Conservation, Land use, Wildlife
Description	This policy brief proposes a siting framework for large-scale solar projects which will produce much needed zero-carbon electricity and can serve important ecosystem enhancement and conservation roles. This paper argues that large-scale solar projects should be designed and operate to maximise preservation of our natural capital and ecosystems and sited to minimise negative impacts on land. The paper describes the decarbonisation challenge, discusses current trends in large-scale solar and storage deployment, puts the acreage need of large-scale solar deployment consistent with decarbonisation goals in the context of other types of land use, offers three foundational principles for siting and introduces a permitting framework to help guide responsible siting.
URL	https://www.seia.org/research-resources/large-scale-solar-siting-encouraging-ecosystem-enhancement-and-conservation

GOOD PRACTICE GUIDELINES FOR OFFSHORE RENEWABLE ENERGY DEVELOPMENTS

Developer	G+ Integrated Offshore Emergency Response (G+ IOER)
Year published	2019
Supply chain stage(s) covered	Operation
Risks addressed	Pollution
Description	The guidelines intend to give responsible organizations a framework for identifying offshore renewable risks and the backup plans needed to enable the right reaction to the possible risks. Although the guidelines do not exclusively cover the environmental and social risks associated with offshore wind energy supply chains, they provide recommendations on environmental risks, especially pollution, in all the stages of life of a wind farm.
URL	https://www.gplusoffshorewind.com/work-programme/workstreams/guidelines

A GOOD PRACTICE GUIDE TO THE APPLICATION OF ETSU-R-97 FOR THE ASSESSMENT AND RATING OF WIND TURBINES NOISE

Developer	Institute of Acoustics (IOA)
Year published	2013
Supply chain stage(s) covered	Operation
Risks addressed	Turbine Noise
Description	This guide presents current good practice in the application of the ETSU-R-97 assessment methodology for all wind turbines developments above 50 kW, reflecting the original principles within ETSU-R-97, and the results of research carried out and experience gained since ETSU-R-97 was published. The noise limits in ETSU-R-97 have not been examined as these are a matter for Government. Summary points in the guide appear in the blue boxes, labelled as numbered Summary Boxes (SB). Additional Supplementary Guidance Notes, published separately to this guide, expand on some of the aspects considered in the guide to further illustrate the general principles. This guide represents good practice as of the date of publication and does not exempt further advances from being used
URL	https://www.ioa.org.uk/sites/default/files/IOA%20Good%20Practice%20Guide%20on%20Wind%20Turbine%20Noise%20-%20May%202013.pdf

BRE NATIONAL SOLAR CENTRE BIODIVERSITY GUIDANCE FOR SOLAR DEVELOPMENTS

Developer	BRE National Solar Centre (NSC)
Year published	2014a
Supply chain stage(s) covered	Operation
Risks addressed	Biodiversity Risks
Description	This document provides guidance to planners and the solar industry on how they can support biodiversity on solar farms. The guidance provided herein has been developed with, and endorsed by, a number of leading UK conservation organisations. The approach to managing biodiversity will be different for every solar farm, and it is recommended that a site-specific plan be devised in each case. The purpose of this document is to support the development of a plan by presenting a broad range of options for biodiversity enhancement and management, and illustrating best practice through a series of case studies. The guidance provided here draws upon good practice from a number of sources, as detailed in the bibliography at the end of this document.
URL	https://www.bre.co.uk/filelibrary/nsc/Documents%20Library/NSC%20Publications/National-Solar-Centre---Biodiversity-Guidance-for-Solar-Developments--2014-.pdf

NATURAL CAPITAL BEST PRACTICE GUIDANCE: INCREASING BIODIVERSITY AT ALL STAGES OF A SOLAR FARM'S LIFE CYCLE

Developer	Solar Energy UK
Year published	2022
Supply chain stage(s) covered	Operation
Risks addressed	Biodiversity Risks
Description	This best practice guidance has been produced to raise awareness and promote the design, construction and operation of high-quality solar farm projects which support ecology and deliver additional benefits arising from multiple land use. It provides detailed guidance on how to deliver a solar farm from site design through to decommissioning with an emphasis on promoting environments which provide natural capital, biodiversity, and in some cases agriculture, alongside green energy supply. Most Local Planning Authorities (LPAs) will by now have some experience with the consenting process for renewable energy technologies, however many may be unaware of the specific opportunities for solar farms to improve biodiversity and increase ecosystem services. Solar farms can be a critical tool for LPAs to achieve both their climate and ecological objectives. Solar farm developers should also find this guide useful in the development, construction, and operation of sites. It has been designed to clearly set out the benefits of implementing biodiversity enhancement strategies alongside maximising the output of solar installations. This has progressed considerably in the past few years, presenting exciting new financial opportunities as well.
URL	https://solarenergyuk.org/resource/natural-capital-best-practice-guidance/

AGRICULTURAL GOOD PRACTICE GUIDANCE FOR SOLAR FARMS

Developer	BRE National Solar Centre
Year published	2014b
Supply chain stage(s) covered	Operation
Risks addressed	Biodiversity Risks, Agriculture, Land use
Description	This document describes experience and principles of good practice to date for the management of small livestock in solar farms established on agricultural land, derelict/marginal land and previously-developed land.

	Proposed for publication as an appendix to existing best practice guidelines by the BRE National Solar Centre, it should be read in conjunction with BRE (2014) Biodiversity Guidance for Solar Developments. The guidance presented here has been developed with, and endorsed by, a number of leading UK solar farm developers and organisations concerned with agriculture and land management.
URL	https://files.bregroup.com/solar/NSC_-Guid_Agricultural-good-practice-for-SFs_0914.pdf

THE CODE OF GOOD PRACTICE

Developer	Polish Wind Energy Association (PWEA)
Year published	2019
Supply chain stage(s) covered	Construction, decommissioning
Risks addressed	Environmental and social issues
Description	The Code defines a framework for wind energy developers to help contribute to the sustainable growth of Poland. The code aims to assist companies in balancing the interests of all stakeholders, including local communities, energy consumers, the environment, government agencies and the general public. With sections covering environment and planning, wind farm decommissioning and public participation, the code offers guidance on both environmental and social issues.
URL	http://psew.pl/en/wp-content/uploads/sites/2/2019/09/Code-of-Good-Practice.pdf

ENVIRONMENTAL, HEALTH, AND SAFETY GUIDELINES FOR WIND ENERGY

Developer	World Bank Group
Year published	2015
Supply chain stage(s) covered	Construction, operation, decommissioning
Risks addressed	Environmental issues (landscape, noise, biodiversity, visual impacts and water quality)
Description	Similar to the G+ IOER report, the guidelines are technical reference guides that provide examples of good international industrial practices for many industries. The performance levels and metrics that are considered feasible in new facilities using current technology at affordable prices are highlighted in the guidelines. They cover a wide range of environmental issues specific to the construction, operation and decommissioning of wind energy projects and facilities, including landscape, noise, biodiversity, visual impacts and water quality.

URL	https://www.ifc.org/wps/wcm/connect/topics_ext_content/ifc_external_corporate_site/sustainability-at-ifc/publications/publications_policy_ehs-wind_energy

END-OF-LIFE MANAGEMENT: SOLAR PHOTOVOLTAIC PANELS

Developer	International Renewable Energy Agency (IRENA), International Energy Agency (IEA)
Year published	2016
Supply chain stage(s) covered	End of life
Risks addressed	Waste management, recycling
Description	Produced in partnership with IEA's Photovoltaic power systems programme (IEA-PVPS), the guidance was the first-ever projection of PV panel waste volumes to 2050. It highlights that recycling or repurposing solar PV panels at the end of their roughly 30-year lifetime can unlock an estimated stock of 78 million tonnes of raw materials and other valuable components globally by 2050. The report provides suggestions to address projected challenges and opportunities surrounding the end-of-life management of PV panels, for example: • Adopt PV-specific waste regulations: Sustainable end-of-life management policies, more data and analyses are needed at a national level to support suitable regulatory and investment conditions • Expand waste management infrastructure: Management schemes for PV waste based on the unique conditions of each country or region, Co-ordination mechanisms between energy and waste sectors • Promote ongoing innovation: R&D and skills development, policy-makers' and PV stakeholders' pro-active preparations for the rise of panel waste With a focus on waste management, the document explains key concepts such as 'reduce, reuse and recycle' and recommends policies to shape the regulations of end-of-life management.
URL	https://www.irena.org/publications/2016/Jun/End-of-life-management-Solar-Photovoltaic-Panels

GUIDELINES FOR ASSESSING END-OF-LIFE MANAGEMENT OPTIONS FOR RENEWABLE AND BATTERY ENERGY STORAGE TECHNOLOGIES

Developer	Electric Power Research Institute (EPRI)
Year published	2021
Supply chain stage(s) covered	End of life

Risks addressed	Waste management, circular economy
Description	This good practice guidance addresses the issues in the end-of-life management of renewables and batteries. A crucial need for electric utilities, it is a compendium of best practices and recommendations for decommissioning renewable and battery energy storage systems. It discusses the fundamental decommissioning process and factors that apply to lithium-ion batteries and renewable energy technologies, provides a list of potential courses of action at the time of technology procurement, and outlines technology-specific procedures once assets have reached their end of life. It is intended to serve as a starting point for learning about disposal, reuse and recycling choices (EPRI, 2021).
URL	https://www.epri.com/research/products/000000003002020594

ACCELERATING WIND TURBINE BLADE CIRCULARITY

Developer	Wind Europe, Cefic, EuCIA
Year published	2020
Supply chain stage(s) covered	End of life
Risks addressed	Recycling
Description	Specific to wind energy, the report presents the state of play in the recycling of composites used in wind turbine blades. The report: • Describes wind turbine blade structure and material composition; • Highlights the expected volumes of composite waste, including wind turbines blade waste; • Maps the existing regulations governing composite waste in Europe; • Describes the existing recycling and recovery technologies for treating composite waste as well as innovative applications for using composite waste; and • Provides recommendations for research and innovation to further enhance the circularity of wind turbine blades, including new materials and design for recycling.
URL	https://windeurope.org/wp-content/uploads/files/about-wind/reports/WindEurope-Accelerating-wind-turbine-blade-circularity.pdf

CIRCULAR PROCUREMENT IN 8 STEPS

Developer	Van Oppen et al. (Copper8)
Year published	2018
Supply chain stage(s) covered	End of life
Risks addressed	Circular economy

Description	The report provides guidance on circular economy for persons responsible for purchasing products for business purposes, relevant to the renewable power generation industry. The guidance recommends eight steps to achieve a circular economy (Van Oppen et al., 2018): • Step 1 establishes the working definition of 'circular economy' regarding the procurement project and why an organization wants to adopt circular procurement • Step 2 starts to establish how to do so • Step 3 helps to achieve a clear picture of an organization's functional demand and how this can best be fulfilled • Step 4 describes why collaboration with suppliers contributes to the circular economy and how these collaborations can be organized • Step 5 offers guidance on considerations to select the tendering procedure • Step 6 will select the appropriate potential suppliers and award the contract to the supplier that submits the most circular tender • Step 7 explores how an organisation can secure circularity in the long term from two perspectives: circular revenue models and circular contracts • Step 8 provides recommendations for circular contract management
URL	https://www.copper8.com/wp-content/uploads/2018/10/Circular-Procurement-in-8-steps-Ebook.pdf

SOLAR PHOTOVOLTAIC MODULE RECYCLING: A SURVEY OF US POLICIES AND INITIATIVES

Developer	National Renewable Energy Laboratory (NREL)
Year published	2021a
Supply chain stage(s) covered	End of life
Risks addressed	Recycling
Description	This report identifies drivers, barriers, and potential enablers to PV module recycling and resource recovery efforts in the United States. In addition to literature-based research, the report contains a number of interviews and interactions with industry stakeholders to identify factors that may drive or act as a barrier to PV module recycling opportunities in the United States. The stakeholder interactions also informed potential solutions to the identified barriers to enable recycling-based recovery of PV module materials in the United States. Some drivers identified for domestic PV module recycling include increased supply chain stability, reduced negative environmental impacts, and new and expanded US market opportunities. Some barriers identified that may impede PV module recycling opportunities in the United States include gaps in data, current recycling technology, services and infrastructure, and regulatory uncertainty. Policy can help enable PV module recycling in the United States. Although, this report is based in the US, its objectives and results can be universally applied to other PV markets.

URL	https://www.nrel.gov/docs/fy21osti/74124.pdf

A CIRCULAR ECONOMY FOR SOLAR PHOTOVOLTAIC SYSTEM MATERIALS: DRIVERS, BARRIERS, ENABLERS, AND US POLICY CONSIDERATIONS

Developer	National Renewable Energy Laboratory (NREL)
Year published	2021b
Supply chain stage(s) covered	End of life
Risks addressed	Circular Economy
Description	Similar to the report above, this report analyses drivers, barriers, and enablers to a circular economy for PV system materials in the United States. It also analyses federal, state, and local requirements that apply to the reuse, recycling, and disposal of PV modules and BOS equipment, as well as the legal liability associated with non-compliance. It then discusses state policies and initiatives in the United States that expressly address reuse, recycling and disposal of PV system equipment. The report concludes by providing case studies of US business models for the repair, reuse, and recycling of PV modules and BOS equipment. The report found that new and expanded market opportunities, job creation, supply chain stability, and reduced negative environmental impacts are drivers for federal, state, and local government investment in the repair, reuse and recycling of PV system equipment. The report found nascent markets for the repair, reuse and recycling of PV in the United States, but there are a number of barriers that impede these options from being a viable alternative to disposal. Policy can help enable a circular economy for PV material in the United States. Although, this report is based in the US, its objectives and results can be universally applied to other PV Solar Markets.
URL	https://www.nrel.gov/docs/fy21osti/74550.pdf

BEST PRACTICES AT THE END OF THE PHOTOVOLTAIC SYSTEM PERFORMANCE PERIOD

Developer	National Renewable Energy Laboratory (NREL)
Year published	2021c
Supply chain stage(s) covered	End of life
Risks addressed	Circular Economy, Recycling

Description	A photovoltaic (PV) power generation project involves design, construction and operation of a PV power plant over a performance period of 20–30 years. The duration of a financial prospectus or power purchase agreement (PPA) often determines the expected performance period. This paper investigates alternatives at the end of that performance period: extending the performance period and refurbishing, repowering or decommissioning the system, as well as laws that can limit these options. This paper describes the need to plan early in project development, issues to consider at the end of the performance period and the pros and cons of alternatives. It also includes recommendations for system owners, asset managers and industry service providers.
URL	https://www.nrel.gov/docs/fy21osti/78678.pdf

SOLAR SUSTAINABILITY: BEST PRACTICES BENCHMARK

Developer	SolarPower Europe
Year published	2021
Supply chain stage(s) covered	Entire Supply Chain
Risks addressed	Circularity, Sustainable Supply Chain, Biodiversity, Human Rights, Supply Chain Transparency, Carbon Footprint
Description	This study aims to provide an overview on sectorial best practices, which fill the sometimes abstract frameworks of standards with life and demonstrate that the industry is continuously evaluating and improving approaches to sustainability. This report, stemming from the collaboration of industry experts in the SolarPower Europe Sustainability Workstream, presents the results of sustainability case studies and best practices along the solar value chain. The sustainability areas addressed in this report are the following: • Carbon Footprint (Chapter 1) • Circularity (Chapter 2) • Sustainable supply chain (Chapter 3) • Biodiversity in large-scale solar (Chapter 4) • Planning and designing for public acceptance (Chapter 5) • Human Rights (Chapter 6) • Supply Chain transparency (Chapter 7) Each chapter firstly defines the context and background following which it provides approaches and best practices, detailing the available sets of action and initiatives for this specific sustainability challenge. Finally, several case studies are outlined, illustrating the implementation of best practices in current, real-world applications.
URL	https://www.solarpowereurope.org/insights/thematic-reports/solar-sustainability-best-practices-benchmark

HOW TO REDUCE THE TOTAL ENVIRONMENTAL, ECONOMIC AND SOCIAL IMPACTS OF SOLAR CELL PANELS

Developer	KTH Royal Institute of Technology
Year published	2021
Supply chain stage(s) covered	Entire Supply Chain
Risks addressed	Circularity, Recycling
Description	The project aims to investigate solar cell panels from production to decommissioning. The investigation considers three flows through the life cycle of the panels—energy, carbon emissions and materials. It also includes two assessments—financial impact and social impact. Research will be done to identify where in the value chain the biggest potential for improvement can be found. The results have been obtained by conducting a literature study, interviewing people with expertise of different parts of the value chain and making calculations to compare and visualise the findings. Two main ways to improve the PV panel's negative impact in terms of environmental, financial and social sustainability have been established. Firstly, the study suggests the importance of implementing advanced recycling within the value chain. Recycling a high percentage of materials in the PV panel, and reusing the recovered material in production will decrease the energy consumption and harmful emissions significantly, alongside increasing circularity of critical materials and bring both financial and social benefits. Secondly, moving the better part of the production to Europe from China would also decrease the environmental and social impact—but there is no financial incentive to do so. Further studies are needed.
URL	https://www.diva-portal.org/smash/get/diva2:1575772/FULLTEXT01.pdf

OECD DUE DILIGENCE GUIDANCE FOR RESPONSIBLE BUSINESS CONDUCT

Developer	Organisation for Economic Cooperation and Development (OECD)
Year published	2018
Supply chain stage(s) covered	Entire Supply Chain
Risks addressed	Due Diligence, Responsible Business Conduct
Description	This Due Diligence Guidance for Responsible Business Conduct (Guidance) is based on the OECD Guidelines for Multinational Enterprises (OECD Guidelines for MNEs). The OECD Guidelines for MNEs are non-binding recommendations addressed to multinational enterprises by governments on responsible business conduct (RBC). This Guidance helps businesses (enterprises) to understand and implement due diligence for RBC as foreseen in the OECD Guidelines for MNEs (due diligence).

	This Guidance also seeks to promote a common understanding amongst governments and stakeholders on due diligence for RBC. The OECD Guidelines for MNEs provide enterprises with the flexibility to adapt the characteristics, specific measures and processes of due diligence to their own circumstances. Enterprises should use this Guidance as a framework for developing and strengthening their own tailored due diligence systems and processes, and then seek out additional resources for further in-depth learning as needed. The primary audience of the Guidance is practitioners tasked with implementing due diligence within an enterprise.
URL	https://www.oecd.org/investment/due-diligence-guidance-for-responsible-business-conduct.htm

RESPONSIBLE BUSINESS CONDUCT FOR INSTITUTIONAL INVESTORS: KEY CONSIDERATIONS FOR DUE DILIGENCE UNDER THE OECD GUIDELINES FOR MULTINATIONAL ENTERPRISES

Developer	Organisation for Economic Cooperation and Development (OECD)
Year published	2017c
Supply chain stage(s) covered	Entire Supply Chain
Risks addressed	Due Diligence, Responsible Business Conduct
Description	This paper provides a resource for institutional investors and their stakeholders to help investors implement the recommendations of the OECD Guidelines along the investment value chain. Specifically, it seeks to assist institutional investors by explaining what due diligence under the OECD Guidelines entails and discussing key considerations for investors at each step of the process. This paper describes due diligence approaches relevant for institutional investment managers and asset owners. It does not outline specific approaches for entities that facilitate investment (e.g., market research providers, investment banks that provide research on listed companies and execute trades, or underwrite new security issuance and provide research for initial public offerings, stock exchanges, index providers, etc.). However, it may be a useful reference for these entities as well since the recommendations of the OECD Guidelines are also applicable to them. Benefits: • Increased ability to implement the OECD Guidelines, as well as the UN Guiding Principles on Business and Human Rights (UNGPs) and other relevant frameworks, such as the UN-supported Principles for Responsible Investment (PRI) • "Knowing and showing" that the investor meets expectations under the OECD Guidelines, and makes a positive contribution to sustainable development • Increased ability to meet expectations of clients (in the case of investment managers) and beneficiaries/members (in the case of asset owners such as pension funds) related to RBC standards (e.g., the OECD Guidelines) • Increased understanding and management of investment risks that may be material
URL	https://mneguidelines.oecd.org/RBC-for-Institutional-Investors.pdf

APPENDIX 7: RESPONSIBLE SOURCING

During the mineral excavation and processing stage, it is essential to tackle the associated environmental and social risks such as air and water pollution, waste management, worker safety, human rights abuses (e.g., child labour, gender discrimination), and corruption. Ensuring that local populations continue to benefit from natural resources should be of utmost importance. With effective regulatory enforcement and standards, supply chain due diligence can be a crucial tool for identifying, assessing and mitigating environmental and social risks, which will increase traceability and transparency (IEA, 2022).

IEA (2022) recommends the following measures to achieve mineral security:

- Establish research and development initiatives for technology innovation in both supply and demand to allow for more efficient use of minerals, material substitution and the release of sizable new sources.
- Scale up recycling to improve the circularity of the metals.
- Encourage improved environmental and social performance to boost volumes of products produced sustainably and ethically and to reduce the cost of sourcing them.
- Improve cross-border cooperation between producers and consumers, based on IEA's energy security framework, which could include actions to:
    - Offer reliable and transparent data.
    - Regularly review potential supply chain vulnerabilities.
    - Encourage knowledge transfer and capacity building to disseminate ethical and sustainable development methods.
    - Provide a level playing field by strengthening environmental and social standards.

Sonter et al. (2020) recommend making policy improvements to prevent the detrimental effects of mining in areas that are crucial for conservation as well as creating the appropriate landscape plans that specifically address present and potential mining concerns. The private sector can work with governments to develop policy improvements. These actions must also be backed up by strong research efforts to fill the gaps in existing knowledge. It is also necessary to develop a systematic understanding of the spatially explicit effects of different mining activities on particular biodiversity features, such as those that occur in marine systems and at different distances from mine sites (rather than within a single predefined distance), as opposed to potential threats, as was the case with this study.

Huber & Steininger (2022) suggests a strategy to look for and use alternative minerals in case of high risk. Below is a table summarising possible substitutes for the minerals currently in demand:

Table 3: Possible substitutes for solar and wind technology minerals

MINERAL	POSSIBLE SUBSTITUTES
TIN (one of the conflict minerals)	Aluminium, plastic, paper, glass, copper-base alloys, carbon nanomaterial substitute
RARE EARTH ELEMENTS	By other rare earth elements, platinum group metals, cerium
COBALT	Iron-phosphorus, cerium, cermet, ceramics, manganese, iron, barium or strontium ferrites, lead, vanadium in paints, nickel, rhodium and titanium-based alloys, nickel
LITHIUM	Calcium, mercury, magnesium, zinc

This is an area that still requires further research to ensure the effectiveness of the possible substitutes. Moreover, it will be crucial to understand if the possible substitutes themselves raise concerns about supply chain risks.

Recycling is the most important strategy to reduce the primary demand for raw materials needed for solar and wind technologies. However, responsible sourcing is needed where supply cannot be met by recycled sources. When supply cannot be met by recycled sources, engaging in responsible sourcing through verified certification schemes and due diligence of supply chains is needed to reduce potential negative social and environmental impacts (Giurco et al., 2019).

Responsible sourcing will be especially important for minerals such as copper, lithium, silver and rare earths because reducing their total demand through substitution and efficiency, and offsetting primary demand through recycling is the most challenging (Giurco et al., 2019).

An IEA report (2022) recommends ensuring environmental and social sustainability in the solar PV supply chain in the following way:

- Strengthen international cooperation on creating clear and transparent standards, taking into account environmental and social sustainability criteria.
- Focus on skills development, worker protection and social inclusion across the solar PV supply chain. Adopt policies promoting employment standards and transparency in order to help improve working conditions.

Ensure PV manufacturing facilities adopt low-carbon and material-efficient manufacturing practices.

APPENDIX 8: GOOD PRACTICES FOR RECYCLING AND CIRCULARITY

Giurco et al. (2019) suggest in their report for the Institute for Sustainable Futures that the two key strategies to promote environmental stewardship and respect for human rights in the supply chain are encouraging recycling and responsible sourcing.

Several studies highlighted the need to recycle materials to reduce the environmental impacts of solar and wind energy. Huber & Steininger. (2022) recommend increasing the recycling rate of the minerals or even solar and wind energy technologies in general to reduce the amount of minerals mined. Mancini & Nuss (2020) recommend using recycled materials to meet demands because they may have less of an impact on the environment than producing primary raw materials. The recycling of batteries has the potential to decrease the amount of scrap, separate battery components, enrich important metals and remove or lessen the threat of environmental waste release. It is necessary to create effective recycling technologies that are committed to both the recovery of precious metals and the disposal of elements that are hazardous to the environment (Larcher & Tarascon, 2014). Siemens Gamesa created the first recyclable blade, which was made accessible for onshore wind power projects in 2021. The recycling of turbine blades has always posed a challenge for the wind industry. Although over 85 per cent of wind turbines may be recycled completely, many blades are dumped in landfills after they have been decommissioned (Siemens Gamesa, 2022). When a wind turbine reaches the end of its life, the RecylableBlade recovery method separates the materials using a mildly acidic solution. Once recycled, such materials can be used in the manufacturing of consumer goods, building, or the automobile industry, among other industrial uses (ibid).

Additionally, ENGIE decommissioned the first wind farm to be linked to France's national grid in Port-La-Nouvelle (Aude) and recycled nearly 96 per cent of its parts. The ZEBRA project, spearheaded by the French research institute IRT Jules Verne, unites all stakeholders in the wind turbine value chain with the goal of commercialising fully recyclable wind turbine blades over a three-year period, which began in 2021. The first blade prototype which is entirely recyclable was successfully released on March 17, 2022 (ENGIE, 2021).

A report by IEA (2022) highlights the following to develop and strengthen recycling capabilities in solar PV technologies:

- Implement comprehensive regulatory frameworks to define stakeholder responsibilities and establish minimum requirements for collection and recycling.
- Support technology development efforts that improve solar PV panel design for recycling, reusability and greater durability.

Norgren et al. (2020) summarise a list of Design for Recycling Principles to increase the quantity and value of materials recovered and reused from end-of-life products:

- Crystalline-silicon PV principles:
  - Durable identification of muddle construction and composition could enable safer and more efficient recycling processes.
  - Backsheet (usually made of a combination of ploymers used to cover the back of solar PV modules) composition has particularly important implications for recyclability.
  - Metal choices can have significant impacts on recycling processes and costs.
  - Minimising laminate use or using reversible laminates can facilitate the disassembly of PV modules.

- Decreasing the number and complexity of module materials presents trade-offs related to recyclability and economics.
- Wind turbine blade principles
  - Some blade materials are more recyclable than others, but blade technologies are changing.
  - Minimise the use of additional blade materials other than resin and fibres.
  - Some blade designs include retention of material value after recycling.

Despite the major advances, it is worth noting that the economics of end-of-life handling isn't very favourable to recycling. For example, in the United States, the cost to waste generators to recycle PV modules is around $15-$45 per module. This is significantly higher than the landfill fee, which is $1-$5 per module (US Department of Energy, 2022).

APPENDIX 9: IMPACT ASSESSMENTS AND DATA GOOD PRACTICES

To lessen the negative environmental effects of offshore wind farms, according to Wind Europe, extensive data about the offshore ecosystem is required. The information can cover a variety of topics, such as species and habitats, as well as the cumulative effect of offshore wind, such as coastline and onshore effects of export cabling. To do this effectively, the offshore wind business should collaborate closely with governments and non-governmental organizations. Governments should make sure that permits and other relevant authorities have the knowledge and resources they need to approve enough sites, according to Wind Europe's regulatory policy recommendation (Freeman et al., 2019).

Wildlife surveys can be conducted during the impact assessments of wind farm installations to understand the birds' breeding and feeding dynamics, which can further help minimise the threats to birds and bats (Hogan, 2020). Despite the literature being less widespread within the solar energy, there are suggestions to minimise the impact of large-scale solar projects. Siting the project on land where the impact on flora and fauna is relatively small can lead to both clean energy production and meeting conservation goals (Cameron et al., 2012).

APPENDIX 10: AGRIVOLTAIC

Agrivoltaics has emerged as a promising approach to improve land productivity and maximise synergies among energy, food and environmental security (Dupraz et al., 2011; Hernandez et al., 2019; Al Mamun et al., 2022). Walston et al. (2022) define agrivoltaic systems as the co-location of ground-mounted solar energy development and one or more of the following agricultural activities: crop cultivation, animal husbandry or habitat enhancement to improve ecosystem services. These types of agrivoltaic systems have been shown to improve efficiencies in land use, water use, and energy generation, as well as demonstrating the feasibility of these dual land uses to mutually benefit various ecosystem goods and services (Barron-Gafford et al., 2019; Hernandez et al.; 2019; Proctor et al., 2021). As larger-scale AV systems are being considered to address the energy and food security needs of larger communities, there is a greater need for partnerships between solar developers, operators and members of the agricultural and natural resource conservation communities. These partnerships can be useful in facilitating the scaling of such systems by identifying cost-effective methods to integrate solar energy development and agricultural activities early in project conceptualisation and design (Walston et al., 2022). Moreover, minimising siting conflict and addressing agricultural communities' concerns will be key in the continued deployment of agrivoltaics, as localised acceptance of solar is a critical determinant of project success. A study by Pascaris et al. (2022) was conducted to assess if public support for solar development increases when energy and agricultural production are combined in an agrivoltaic system. Results show that at least 82 per cent of respondents would be more likely to support solar development in their community if it integrated agricultural production. Survey respondents prefer agrivoltaic projects that:

- Are designed to provide economic opportunities for farmers and the local community
- Are not located on public property
- Do not threaten local interests
- Ensure fair distribution of economic benefits

APPENDIX 11: GUIDANCE FOR ADDRESSING SOCIAL RISKS

SUPPLY CHAIN RISK	GOOD PRACTICE/S	KEY CONSIDERATIONS
SOURCING		
Poor working conditions/Lack of Safety Standards		
Human Rights Violations	OECD (2016), RCI & RMI (2022), RMI (2018)	Transparent mineral supply chains, Sustainable corporate engagement, Conflict-affected and high-risk areas, Due Diligence, Cobalt, Tin, Tantalum
Lack of transparency/corruption	RCI & RMI (2022), GIZ & Mining Shared Value (2017)	Conflict-affected and high-risk areas, Due Diligence, Cobalt, Local Procurement Disclosure
Child Labour	GIZ & Mining Shared Value (2017), OECD (2017), TSM Initiative (2018), GRI (2016), IRMA (2018)	Local Procurement Disclosure, Due Diligence, Responsible Sourcing, Performance measurement, Disclosure, Social Responsibility
Labour/Community Health and Safety issues	TSM Initiative (2018), IRMA (2018), ICMM (2022)	Social Responsibility, Performance measurement
Gender Discrimination		
Forced Labour	GIZ & Mining Shared Value (2017), TSM Initiative (2018), GRI (2016), IRMA (2018)	Local Procurement Disclosure, Performance measurement, Due Diligence, Disclosure, Social Responsibility
Displacement of indigenous communities	OECD (2017), TSM Initiative (2018)	Stakeholder Engagement, Responsible Business Conduct, Thematic Guidance, Due Diligence
Heavy Metal Toxicity		
Air Pollution	IRMA (2018)	Performance measurement
Water Stress/Water contamination	TSM Initiative (2018), IRMA (2018)	Performance measurement, Environmental Responsibility
Waste	IRMA (2018)	Performance measurement
Climate Change impacts – extreme heat/droughts	TSM Initiative (2018)	Performance measurement

SUPPLY CHAIN RISK	GOOD PRACTICE/S	KEY CONSIDERATIONS
Biodiversity risks	TSM Initiative (2018), IRMA (2018), ICMM (2022)	Performance measurement, Environmental Responsibility
Habitat loss and fragmentation/ Forest loss and degradation		
Soil and groundwater acidification		
Deep-sea mining		
MANUFACTURING AND CONSTRUCTION		
Land use risks (social – e.g., conflict with farmers, communities etc.)		
Land use risks (environment – e.g., erosion etc.)		
Sedimentation		
Construction noise	IUCN et al. (2021)	Guidelines for project developers
Habitat loss, degradation and fragmentation		
Biodiversity risks	Ipieca (2020), IUCN et al. (2021)	Responsible environmental management, Guidelines for project developers
Water stress/Water contamination	Ipieca (2020), IUCN et al. (2021)	Responsible environmental management, Guidelines for project developers
Chemicals (Fluorine, Chromium)		
Human rights violations	Ipieca (2020)	Responsible social management
Labour/Community Health and Safety issues	Ipieca (2020)	Responsible social management
Displacement of indigenous communities	OECD (2017), TSM Initiative (2018)	Stakeholder Engagement, Responsible Business Conduct, Thematic Guidance, Due Diligence

SUPPLY CHAIN RISK	GOOD PRACTICE/S	KEY CONSIDERATIONS
OPERATIONAL		
Human rights violations	Ipieca (2020)	Responsible social management
Labour/Community Health and Safety issues	Ipieca (2020)	Responsible social management
Collision, displacement and habitat changes (birds and bats)	IUCN et al. (2021)	Guidelines for project developers
Impact on bird migration patterns		
Electromagnetic field impact on crustaceans		
Biodiversity risks	Ipieca (2020), IUCN et al. (2021)	Responsible environmental management, Guidelines for project developers
Water stress/water contamination	Ipieca (2020), IUCN et al. (2021)	Responsible environmental management, Guidelines for project developers
Impact on fishing communities		
END OF LIFE		
Solid waste/Hazardous solid waste	EPRI (2021), Copper8 (2018)	Waste management, circular economy
Health impacts		
Ecological Damage		
Noise		

Solar technology good practices

SUPPLY CHAIN RISK	GOOD PRACTICE/S	KEY CONSIDERATIONS
SOURCING		
Human Rights violations	SEIA (2021)	Code of Conduct
Labour/Community Health and Safety issues	SEIA (2021)	Code of Conduct
Forced Labour	SEIA (2021)	Code of Conduct
Air Pollution	SEIA (2021)	Code of Conduct
Water Stress/Water contamination	SEIA (2021)	Code of Conduct
Waste	SEIA (2021)	Code of Conduct
Climate Change impacts	SEIA (2021)	Code of Conduct
MANUFACTURING AND CONSTRUCTION		
Human Rights violations	SEIA (2021)	Code of Conduct
Labour/Community Health and Safety issues	SEIA (2021), SolarPower Europe (2021)	Code of Conduct, Due Diligence
Forced Labour	SEIA (2021)	Code of Conduct
Air Pollution	SEIA (2021)	Code of Conduct
Water Stress/Water contamination	SEIA (2021)	Code of Conduct
Waste	SEIA (2021)	Code of Conduct
Climate Change impacts	SEIA (2021)	Code of Conduct
Biodiversity Risks	SSII (2022)	Siting Framework
Land Use Risks	SSII (2022)	Siting Framework
OPERATIONAL		
Human Rights violations	SEIA (2021)	Code of Conduct
Labour/Community Health and Safety issues	SEIA (2021), SolarPower Europe	Code of Conduct, Due Diligence

SUPPLY CHAIN RISK	GOOD PRACTICE/S	KEY CONSIDERATIONS
Forced Labour	SEIA (2021)	Code of Conduct
Air Pollution	SEIA (2021)	Code of Conduct
Water Stress/Water contamination	SEIA (2021)	Code of Conduct
Waste	SEIA (2021)	Code of Conduct
Climate Change impacts	SEIA (2021)	Code of Conduct
Biodiversity Risks	SSII (2022), BRE NSC (2014a), Solar Energy UK (2022), BRE NSC (2014b)	Siting Framework, Guidance to planners and the solar industry
Land Use Risks	SSII (2022), BRE NSC (2014b)	Siting Framework
END OF LIFE		
Solid Waste/Solid Hazardous Waste	IRENA & IEA (2016), NREL (2021a), NREL (2021b), NREL (2021c)	Waste management, recycling
Land use competition (mostly for agricultural land)		
Degradation of vegetation		
Biodiversity Loss		
Water Pollution		
Soil Contamination		
Thermal and Air Pollution		
Habitat Fragmentation		
ENTIRE SUPPLY CHAIN		
Human rights violations	SolarPower Europe (2021)	Sectorial best practices
Lack of transparency/Corruption	SolarPower Europe (2021)	Sectorial best practices
Biodiversity Risks	SolarPower Europe (2021)	Sectorial best practices
Solid Waste/Hazardous Solid Waste	SolarPower Europe (2021), KTH Royal Institute of Technology (2021)	Sectorial best practices, Circular Economy, Recycling

Wind technology good practices

SUPPLY CHAIN RISK	GOOD PRACTICE/S	KEY CONSIDERATIONS
MANUFACTURING AND CONSTRUCTION		
Air Pollution	NatureScot (2019)	Peer learning
Water Stress/Water contamination	NatureScot (2019), World Bank Group (2015)	Peer learning, Technical guidelines
Biodiversity Risks	NatureScot (2019), World Bank Group (2015)	Peer learning, Technical guidelines
Impact on fishing communities	Ipieca (2023)	Social baseline data collection processes
Noise	World Bank Group (2015)	Technical guidelines
OPERATIONAL		
Air Pollution	NatureScot (2019), G+ IOER (2019)	Peer learning, Risk Framework
Water Stress/Water contamination	NatureScot (2019), World Bank Group (2015)	Peer learning, Technical guidelines
Biodiversity Risks	NatureScot (2019), World Bank Group (2015)	Peer learning, Technical guidelines
Impact on fishing communities	Ipieca (2023)	Social baseline data collection processes
Turbine noise	IOA (2013), World Bank Group (2015)	Noise assessment
END OF LIFE		
Water Stress/Water contamination	World Bank Group (2015)	Technical guidelines
Biodiversity Risks	World Bank Group (2015)	Technical guidelines
Noise	World Bank Group (2015)	Technical guidelines
Impacts on marine mammals, subtidal benthos, commercial fisheries		
Impacts on landscape and visual	World Bank Group (2015)	Technical guidelines

SUPPLY CHAIN RISK	GOOD PRACTICE/S	KEY CONSIDERATIONS
Impacts on physical processes – Changes to sediment movements, mobilisation of contaminants etc.		
Impacts on benthic ecology – Habitat loss, impact of noise on fish and marine mammals etc.		
Solid Waste/Solid Hazardous Waste	Wind Europe et al. (2020)	Recycling

APPENDIX 12: ACTIONS TAKEN BY RENEWABLES COMPANIES TO MANAGE ENVIRONMENTAL AND SOCIAL RISKS

COMPANY	ACTIONS	DESCRIPTION	SOURCE/LINK
ALGONQUIN	Supplier Code of Conduct	Sets out the core values and corporate practices expected from their suppliers, vendors, and partners. Seeks out opportunities to collaborate with, provide input to, and seek guidance from vendors on end-of-life recycling and sustainable disposal programs.	Algonquin 2021 ESG Report
BROOKFIELD RENEWABLE	ESG Due Diligence and Supply Chain Due Diligence Guidelines	Helps to identify, prevent, mitigate and respond to the potential human rights and impacts within potential investments.	Brookfield Renewable 2021 ESG Report
CANADIAN SOLAR	Supplier Code of Conduct	Establishes standards on human rights, environmental protection, health, safety and business ethics to maintain a responsible supply chain. This code is used as part of due diligence in assessing new suppliers.	Canadian Solar 2021 ESG Report
CANADIAN SOLAR	Supplier ESG Auditing Program	Covers quality control, environment, health, safety, human rights, business ethics and other sustainability aspects based on their Supplier Code of Conduct.	Canadian Solar 2021 ESG Report

COMPANY	ACTIONS	DESCRIPTION	SOURCE/LINK
CANADIAN SOLAR	Conflict Minerals Policy	Supports the goal of the Dodd-Frank Act of preventing armed groups in the DRC and adjoining countries from benefitting from the sourcing of Conflict Minerals from that region.	Canadian Solar 2021 ESG Report
CONSTELLATION	Supplier Code of Conduct	Outlines its expectations and standards for ethical conduct and is grounded in the values Constellation employees live by every day. Also describes expectations for suppliers to uphold human rights of all workers.	Constellation 2022 Sustainability Report
EDP RENEWABLES	Human and Labour Rights Policy	Aims to ensure respect for Human and Labour Rights in EDPR's sphere of activity, implementing the commitments defined in its policies, specifying the international reference treaties and standards and establishing the procedures that ensure compliance with them.	EDP renewables Human and Labour Rights Policy 2022
GE	Human Rights Statement of Principles	Reflects GE's commitment to respect fundamental labour rights including the prohibition of forced and child labour in GE operations and those of their suppliers.	GE 2021 Sustainability Report
GE	Ethical supply chain and responsible mineral sourcing at GE	Since 2002, GE has implemented an extensive supplier responsibility governance (SRG) program to build and strengthen an ethical, sustainable and transparent global supply chain and establish clear social and environmental responsibility requirements for suppliers.	GE 2021 Sustainability Report
GE	Conflict Minerals Policy	Describes the due diligence performed for 2021, including steps taken to mitigate the risk that 3TG in their products benefit armed groups. Also describes the products that they have reason to believe might contain 3TG originating from the Covered Countries and information about the processing facilities and countries of origin of 3TG used in those products.	GE 2021 Conflict Minerals Report

COMPANY	ACTIONS	DESCRIPTION	SOURCE/LINK
HITACHI ENERGY	Conflict Minerals Policy	Addresses conflict minerals sourced from Democratic Republic of Congo and its adjoining countries: Establishes a "Conflict Minerals Compliance Program" supported by Hitachi Energy Executive Committee to review the use of Conflict Minerals in their products and respond to customer inquiries. Developed based on the OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict Affected and High-Risk Areas and other appropriate international standards.	Hitachi Energy Conflict Minerals Policy
IBERDROLA	Biodiversity Policy	Involves integrating biodiversity into strategic planning, managing risk through continuous assessment of impacts and dependencies throughout the life cycle, applying the mitigation hierarchy in all their activities, avoiding the placement of new infrastructure in protected areas, implementing biodiversity action plans, working together with stakeholders, and encouraging awareness and communication	Iberdrola Statement of Non-Financial Information Sustainability Report Financial Year 2021
IBERDROLA	Environmental Management System.	Enables the alignment of the environmental dimension with the group's sustainability model, integrating the SDGs and coordinating the mechanisms for measuring and assessing the group's environmental performance in terms of the life cycle, including the concepts of circular economy and natural capital in the group's management.	Iberdrola Statement of Non-Financial Information Sustainability Report Financial Year 2021
IBERDROLA	Corporate Environmental Footprint	To gauge the group's environmental performance, Iberdrola calculates its Corporate Environmental Footprint (CEF), which evaluates the effects of the company's activities on the environment from a life cycle viewpoint (ISO/TS standard 14072:2014)	Iberdrola Statement of Non-Financial Information Sustainability Report Financial Year 2021

COMPANY	ACTIONS	DESCRIPTION	SOURCE/LINK
IBERDROLA	Human Rights Due Diligence System	Iberdrola's Human Rights Due Diligence System seeks to promote the implementation of the Guiding Principles (Principle 18.a of the UNGPs) adjusted for the size of the company and the diversity and particularities of the facilities in the various countries.	Iberdrola Statement of Non-Financial Information Sustainability Report Financial Year 2021
JINKOSOLAR	Supplier Conduct Codes	In the selection of procurement categories, the following factors should be given priority: • Use the least raw materials. • Give priority to recycled material. • Promote suppliers to simplify packaging and recycle packaging materials.	Iberdrola Statement of Non-Financial Information Sustainability Report Financial Year 2021
NEXTERA ENERGY	Code of Business Conduct and Ethics	Commitment to human rights extends to their international suppliers and works closely with their solar panel and energy storage suppliers to protect that their equipment, including components, are produced without forced labour.	Nextera Energy 2022 Environmental, Social and Governance Report
ORSTED	Global human rights policy	Committed to respecting human rights in everything they do. They want to proactively address any potential risks of negative impacts on human rights and be transparent about their efforts and challenges along the way. They are now working to further develop and strengthen their human rights due diligence approach for all of their rightsholder groups including employees, local communities, and people in their supply chains.	Orsted Sustainability Report 2022
RWE	"Care Commitments" in the HSE Policy Statement	Defined their principles and values for the activities of RWE Renewables in the "Care Commitments." These form the basis for their activities, starting with the planning of new assets through to operation and decommissioning and entails evaluation of negative impacts on species diversity and in preliminary studies and environmental compliance studies.	RWE Sustainability Report 2021

COMPANY	ACTIONS	DESCRIPTION	SOURCE/LINK
RWE	Biodiversity Policy	Describes the approach of RWE to the protection and promotion of biodiversity in the Rhenish lignite mining region	RWE Sustainability Report 2021
RWE	Due Diligence	Based on a risks analysis, it was established that risks with negative impacts are generally not expected in their direct business relationships but more particularly in the deeper supply chain.	RWE Sustainability Report 2021
SIEMENS GAMESA	Supplier Relationship Policy	Provides a group-wide framework for the management and oversight of procurement activities.	Siemens Gamesa Consolidated Non-Financial Statement 2021
SIEMENS GAMESA	Code of Conduct for Suppliers and Third-Party Intermediaries	Sets out the Group's binding requirements and translates their requirements into contractual obligations. Based on the UN Global Compact and the principles of the ILO, the principles of the Rio Declaration on Environment and Development, etc. Establishes standards to ensure that working conditions in the supply chain are safe, that workers are treated with respect and dignity, and that transactions with suppliers are ethical and socially and environmentally responsible.	Siemens Gamesa Consolidated Non-Financial Statement 2021
SIEMENS GAMESA	Supply Chain Due Diligence	Committed to responsible sourcing of minerals, especially from conflict or high-risk areas according to the OECD Due Diligence Guidance. Conducting a uniform-wide process to determine the use, source and origin of the relevant minerals in their supply chain.	Siemens Gamesa Consolidated Non-Financial Statement 2021
SIEMENS GAMESA	Sustainability Policy	Outlines broader ambitions related to decarbonisation, circularity and biodiversity protection and climate change.	Siemens Gamesa Consolidated Non-Financial Statement 2021

COMPANY	ACTIONS	DESCRIPTION	SOURCE/LINK
SIEMENS GAMESA	Sphera, an internal HSE software tool	Allows for data collection and analysis including: • Reporting figures such as energy use and sources, waste amounts and disposal destinations, water use, environmental incidents, etc. • Monitoring environmental data and trends, and visualising them to better support analysis. • Providing transparency and opportunities for sharing best practices.	Siemens Gamesa Consolidated Non-Financial Statement 2021
SUNPOWER	Supplier Sustainability Guidelines	Based on the SEIA's Solar Commitment, defines common practices and expectations for all solar industry participants, including manufacturers, suppliers, subcontractors and customers in the solar value chain.	SunPower ESG Report 2021
SUNPOWER	Human Rights Statement	Sets out expectations for third parties with whom they do business and guides their employees on due diligence in relation to vendors and service providers.	SunPower ESG Report 2021
SUNPOWER	Conflict Minerals Policy	Expects its suppliers to have conflict mineral policies and due diligence measures that give them reasonable assurance that minerals used are conflict-free, including passing the same requirements on to their suppliers. Fully supports the goals and objectives of Dodd-Frank federal legislation in the US.	SunPower ESG Report 2021
TPI	Human Rights and Supplier Due Diligence	Addresses areas such as child labour, corruption, safety, and sustainability. Recommends using an independent vendor assessment tool, conducting audits for their suppliers, and communicating TPI's expectations for compliance and ethical behaviour in their Supplier Code of Conduct and Human Rights Policy.	TPI 2021 ESG Report
TPI	EHS Policy	Helps guide all TPI activities to maximise the positive impacts that they have on the environment through both the products they manufacture and how they manufacture them.	TPI 2021 ESG Report

COMPANY	ACTIONS	DESCRIPTION	SOURCE/LINK
VESTAS	Supplier Code of Conduct	Prepared in accordance with the UN Global Compact, the International Bill of Human Rights, and International Labour Organisation conventions and guided by the OECD's Guidelines for Multinational Enterprises on responsible business conduct. Outlines the minimum requirements suppliers must adhere to when conducting business with Vestas.	Vestas Sustainability Report 2021
VESTAS	Supply Chain Due Diligence on Conflict Minerals	Conducts supply chain due diligence on conflict minerals, following the OECD Due Diligence Guidance for Responsible Supply Chains of Minerals. This process does not contain minerals sourced from mines associated with conflict in the DRC or adjoining countries, or with other illegal activities.	Vestas Sustainability Report 2021
VATTENFALL	Biodiversity footprint assessment	A 2021 corporate-wide biodiversity footprint assessment, using the Global Biodiversity Score tool, which enabled them to quantify the biodiversity impacts of their economic activities along the value chain.	Vattenfall Annual and Sustainability Report 2021
VATTENFALL	Code of Conduct for Suppliers	Defined the company's basic requirements and expectations for their suppliers with respect to sustainability	Vattenfall Annual and Sustainability Report 2021
VATTENFALL	Due Diligence processes	Designed to identify and assess human rights, environmental and business ethics-related risks and impacts across their value chain.	Vattenfall Annual and Sustainability Report 2021
VATTENFALL	Supplier Risk Assessment Tool (SRAT) Light	Facilitates the initial risk assessment of new suppliers based on spend, product category and country risk.	Vattenfall Annual and Sustainability Report 2021

Managing social risks

A scan of at least 20 sustainability/ESG reports of renewables companies shows strong efforts to manage suppliers, at least in respect to tackling social risks. The three most common tools/actions implemented by the companies to manage their supply chains are Supplier Code of Conduct, Due Diligence Guidelines, and Human and Labour Rights Policy. These cover a range of social risks identified in this report such as human rights violations, labour working conditions, child labour, forced labour, conflicts, etc. Many companies have either stopped or reduced their supply from suppliers associated with evidence of human rights violations.

Managing sourcing risks

A few companies have conflict minerals policies and ethical supply chain and responsible mineral sourcing policies. The Conflict Mineral Policy requires the companies' compliance with the rules implementing Section 1502 of the Dodd-Frank Wall Street Reform and Consumer Protection Act of 2010 (the "Dodd-Frank Act") adopted by the US Securities and Exchange Commission. The Rule requires disclosure of the use of Conflict Minerals sourced from the Democratic Republic of the Congo and its neighbouring countries. There are Ethical Supply Chain auditing programs and due diligence of suppliers in place for a few companies to proactively address social risks and ensure responsible mining sourcing. Most of the Conflict Minerals principles are in line with the guidelines of the OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas (CAHRAs).

Managing environmental risks

There aren't many proactive policies among companies to manage supply chain environmental risks. However, there are a few notable actions, including the Biodiversity Policies of Iberdrola and RWE, which promote strategic planning and continuous assessment throughout the life cycle, applying the mitigation hierarchy, and avoiding the placement of new infrastructure in protected areas. Siemens Gamesa's Sustainability Policy outlines broader ambitions related to biodiversity protection and climate change. A unique tool for environmental risk management is the Vattenfall's Biodiversity footprint assessment, which has enabled the company to quantify the biodiversity impacts of its economic activities along the value chain.

Guidance documents for social risks

Some of the metrics/guiding principles that the solar and wind companies have been referencing are as follows:

- UN Guiding Principles on Business and Human Rights
- OECD Guidelines
- The ten principles of the United Nations Global Compact
- International Bill of Human Rights
- ILO Declaration on Fundamental Principles and Rights at Work
- UN Sustainable Development Goals
- International Organisation for Standardisation
- Global Reporting Initiative
- Sustainability Accounting Standards Bo

Part two: Carbon footprint management for wind and solar

APPENDIX 13: CARBON FOOTPRINT OF WIND AND SOLAR TECHNOLOGIES

Based on a wind farm's theoretical annual generating capacity of 11.843 million kWh and its operating cycle of 20 years, it can be concluded that the carbon emission per unit of wind power generation during the whole life cycle of a wind farm is 4.429/kWh (theoretical value). Around 70 per cent of carbon is emitted during the production phase and around 14 per cent during the construction phase (Li et al., 2020). A Life Cycle Assessment (LCA) study conducted by Raadal et al. (2011) covering the period between 1990 and 2010 found that GHG emissions from wind power differed from 4.6 to 55.4 g CO_2eq/kWh. A recent study by Marshali et al. (2022) concluded the total GHG impact of onshore wind to be 12.7 gCO_2eq/kWh and 13.91 gCO_2eq/kWh for offshore wind with a mean for wind energy technologies to be 13.45 gCO_2eq/kWh. The study further highlighted that the manufacturing stages accounted for between 90 and 98 percent of the overall Global Warming Potential (GWP) of an onshore wind farm,while accounting for 70 per cent of an offshore farm, with most of this impact occurring during material extraction and component manufacturing. Infrastructure related to steel production was the main contributor to the overall GHG emissions (Marshali et al., 2022). Concrete and steel were on average 75 per cent and 23 per cent by weight of the total materials used in onshore turbines, and an average of 39 per cent and 26 per cent in case of offshore turbines. Steel is the major contributor to GWP (48-85 per cent for onshore and 54.5-83.9 per cent for offshore), even though concrete is the material with the highest mass intensity—so steel and concrete need the most attention for mitigation. (Farina & Anctil, 2022).

An LCA conducted for the solar PV projects throughout New York state found the total GHG emissions with a mean of 45.6 gCO_2/kWh (Ali et al., 2022). Another study concluded that PV power facilities have carbon footprints ranging from 12g per kWh to 24g per kWh (Wade, 2016). A study by Hsu et al. (2012) found the median value of GHG emissions from 42 case studies to be 40-47 gCO_2eq/kWh . A recent study by Marshali et al. (2022) concluded the overall GHG impact of solar system technologies to be 38.8 gCO_2eq/kWh.

LCA studies show that, on average, more than 80 per cent of the environmental impact of solar PV is due to the production process of the included modules (Torres & Petrakopoulou, 2022). The manufacturing process of crystalline silicon modules require a large energy input due to the intensive purification of silicon and wafer processing and hence, the environmental impact of the process depends strongly on the electricity mix considered in each study (Torres & Petrakopoulou, 2022). For instance, a 1.8 MW PV facility in Italy with imported modules from China results in a GWP of 88.7 g CO_{2eq}/kWh (Desideri et al., 2012). As a comparison, a 5 MW solar plant in France with European PV modules has a GWP of 37.5 g CO_{2eq}/kWh (Beylot et al., 2014). The manufacturing process of the supporting structure is also important because it is commonly made of aluminium or steel (Torres & Petrakopoulou, 2022). For a 30 MW PV-utility, 1500 t of steel for the mountings are needed, and considering that every ton of steel can produce up to 1.85 tonnes of CO_2 on an average, steel use increases the GWP of PV solar plants (Chen et al., 2022; World Steel Association, 2021 & Beylot et al., 2014).

Onshore wind farms have the lowest GWP when compared to PV solar and offshore wind farms (Marshali et al., 2022). Onshore wind farms produce up to 5 times less GHGs than PV solar farms and up to 1.5 times less than offshore wind farms (UNECE, 2021). Wind power as a whole has lower carbon emission intensities than the other three renewable energy sources of hydropower, biomass, and photovoltaics. When generating one kWh of electricity, the average carbon emissions from hydropower, biomass, and photovoltaic power are 1.90 times, 8.11 times, and 4.62 times that of wind power, respectively (Liu et al., 2021). The findings from the study by Marshali et al. (2022) indicate that raw material acquisition/manufacturing for wind and solar technologies contributes the most to total GWP impacts, accounting for up to 98 per cent of the life cycle stages, followed by installation, operation and maintenance. Another finding worth noting from the study above is that the GHG emissions associated with the life cycle of solar power systems and wind power systems have decreased significantly during the past two decades, reaching 38.88gCO_2eq/kWh and 13.45 gCO_2eq/kWh in 2020, respectively. A few of the possible reasons could be increased awareness of sustainability practices, responsible sourcing, innovation, recycling and circularity.

APPENDIX 14: OPPORTUNITIES TO REDUCE THE CARBON FOOTPRINT OF SOLAR AND WIND TECHNOLOGIES

Magnitude of the installation of solar and wind energy systems: Large, high-capacity wind and solar projects produce much fewer GHGs per unit of power. As the majority of GHGs for PV solar and wind are produced during the extraction, manufacturing and installation processes, the lifespan of solar and wind energy systems also significantly affects GHG emissions. Therefore, the GHG emissions across the entire life cycle are lower the longer the life of a project (Hamed & Alshare, 2022). According to Nugent & Sovacool (2014), a wind system with a 20-year life expectancy emits an average of 40.7 g CO_2/kWh, while one with a 30-year life expectancy emits just 25.3 g CO_2/kWh.

Location: Location of a wind farm affects its produced GHG emissions, meaning siting of these projects is important. The lowest carbon emission intensity is found in grassland wind farms, with average values of 7.91 gCO_2/kWh and 5.74 g CO_2/kWh lower than offshore (19.18 g CO_2/kWh) and onshore non-grasslands (13.65 g CO_2/kWh) (Liu et al., 2021). This is due to a number of factors. The marine environment where offshore wind farms are located has greater needs for wind power equipment and building materials in terms of transport, cabling and construction, resulting in larger carbon footprints and a higher carbon emission intensity (Nugent & Sovacool, 2014; Yang et al., 2018).

While offshore wind projects have a higher carbon footprint than their onshore counterparts, this difference is frequently offset by the greater wind resource, which results in a higher yield of renewable electricity and, as a result, a nearly identical energy payback period. To re-evaluate the advantages of relocating from onshore to offshore locations, new developments in the field of offshore technology, such as an increase in turbine size and novel concepts (such as floating plants), which will contribute to the exploitation of wind resources at greater distances from shore and further reduce GHG and energy intensity, should be monitored and considered (Kaldellis & Apostolou, 2017).

Manufacturing: Through their LCA study, Xu et al. (2018) found that the production process, which may be attributed to the significant input of raw materials, was the major contributor to all environmental effect indicators, including the Global Warming Potential (GWP). Li et al. (2020) found that the material production phase, with 11,123 tCO_2, accounting for 70.61 per cent of the total carbon emissions, contributes the most to emissions in the life cycle of a 49.5 MW wind power project. Vestas' LCA (2018) found that raw material and component production dominate the environmental impacts, including Global Warming Potential of the Vestas V120-2.0 MW wind turbine. Production of the tower, nacelle, blades and foundations contribute most significantly to all studied environmental impact indicators. Even in terms of phase-wise energy and emission intensity of PV solar, the production phase accounts for 55-75 per cent of the total embodied energy requirement and GHG emissions, depending on the PV technology and mode of installation (Prabhu et al., 2022).

The optimisation of the structural design and the efficient application of raw materials are suggested as effective measures to improve the environmental performance of solar and wind energy (Xu et al., 2018).

Electricity-intensive solar PV manufacturing is mostly powered by fossil fuels, but solar panels only need to operate for 4-8 months to offset their manufacturing emissions. Diversification of supply chains and the decarbonisation of the power sector could rapidly reduce solar PV manufacturing emissions. Building solar PV manufacturing around low-carbon industrial clusters such as renewable-based hydrogen can unlock the benefits of economies of scale, enabling them to benefit from cost-competitive renewable electricity (IEA, 2022).

Solar energy land use: For sources of renewable energy other than bioenergy, land requirements and the associated environmental impacts remain understudied in the literature from a quantitative point of view (Capellán-Pérez et al., 2017; Gasparatos, 2017). At the time of writing this literature review, Van de Ven et al. (2021) is the only study (even to the author's knowledge) that has estimated the land cover impacts and related land-use change emissions of solar energy within climate change mitigation scenarios up to 2050.

Van de Ven et al. (2021) discovered that solar energy may occupy 0.5–5 per cent of all land at a 25–80 per cent penetration in the electrical mix of the EU, India, Japan and South Korea. Depending on the region, the scope of the growth, the effectiveness of the solar technology and the land management procedures used in solar parks, the consequent changes to the land cover, including indirect effects, will likely result in a net release of carbon ranging from 0-50 gCO_2/kWh. To prevent a major increase in the life cycle emissions from terrestrial carbon losses, coordinated planning and control of future solar energy infrastructure should be in place. By implementing land management techniques that allow carbon sequestration in solar land, the terrestrial portion of the solar energy life cycle emissions could be completely avoided (van de Ven et al., 2021). An interesting finding from the study is that the land requirements for reaching certain levels of electricity penetration with solar energy are about a magnitude lower than land requirements to meet those same levels with bioenergy. Also, the payback period of bioenergy is significantly higher (~ 4 years) than that of solar energy (< 8 months).

Recycling, life extension and innovation: Bang et al. (2019) recommend focusing on the manufacturing and recycling phases and prioritising factors influencing capacity factor (measurement of how often a plant is running at maximum power) and operational lifetime of the wind farm for effective LCA of GHGs for floating offshore wind energy. When compared to component manufacturing using primary raw materials, recycling wind turbines at the end of their lives can save at least 30-35 per cent of carbon emissions equivalent per kWh. Increasing the lifespan of wind farms through proactive operations and maintenance and repowering are also recognised as appropriate paths to explore further as ways to lower the industry's carbon impact (Spyroudi, 2021; Mali & Garrett, 2022). According to Torres & Petrakopoulou (2022) the most effective factor to improve the overall environmental performance of wind energy systems is the recycling rate of the materials used in the manufacturing process. The best results come from recovering the steel, copper, aluminium and cast iron used in the nacelle and tower from wind power plants with recycling rates higher than 90 per cent (Bonou et al., 2016; Xu et al., 2019). Other studies also highlight that if the end-of-life comprised recycling stage is included in the calculation of LCAs, then the total GWP declined up to 40 per cent (Mali & Garrett, 2022; Chipindula et al., 2022; Xie et al., 2020; Bang et al., 2019).

A study by Prabhu et al. (2021) finds that 90.7 per cent of the PV waste resulting from 95 GW worth of solar PV can be recovered at end of life. This includes a substantial portion of aluminum and glass, the most energy-intensive components of a solar PV module. Another study by Huang et al. (2017) highlights that the recycling of crystalline silicon technologies is reported to lower the GWP by 35 per cent. However, in PV plants, the recycling rate should be close to 95 per cent to significantly decrease the environmental impact, especially due to the recovery of silicon wafers and aluminium frames (Torres & Petrakopoulou, 2022). Moreover, the electricity mix needs to have a high renewable share to reduce the GWP and fossil fuel depletion of the electricity needed in the manufacturing process of PV modules (Huang et al., 2017).

The large amount of steel used in the construction of an offshore wind platform is responsible for the greatest impact of the entire project; so recycling the building materials can be an effective solution to make offshore wind farms more sustainable and reduce their carbon footprint (Ferraz de Paula & Carmo, 2022). For a wind farm of 49.5 MW, recycling of resources such as steel and copper can reduce up to 5261 tonnes of carbon emissions (Li et al., 2020). However, because the technology for producing renewable electricity is still relatively new, concepts for recycling still need further development if many plants are to be deconstructed (Lieberei & Gheewala, 2016).

Despite the nascent recycling stage, there have been a few interesting developments in the field. The emergence of green steel may also be advantageous for wind farms. Swedish companies Hybrit and H2 Green Steel are investing billions of dollars to produce millions of tonnes of green steel annually. They will employ green hydrogen electrolysis using renewable power instead of burning metallurgical coal to light a conventional blast furnace to convert iron ore into pig iron. These businesses are also working to recycle used solar PV panels and turbine blades to reduce the carbon footprint of wind and solar systems (Helman, 2021). Making the steel 'green' will especially be key to reducing carbon emissions. Steel is one of the world's biggest polluting industries, responsible for more than 7 per cent of global CO_2 emissions (H2, n.d.). Switching to hydrogen-based steel production offers an immediate CO_2 emissions reduction opportunity for new assets of 20 per cent and 40 per cent in the United States and the European Union, respectively (Blank, 2019).

Although solar and wind companies have made significant advances in recycling and circularity, innovation and technology are relatively more advanced in wind than in solar. Companies such as Brookfield Renewables, EDPR, GE, Orsted, RWE, Siemens Gamesa, Vattenfall and Vestas have accelerated progress towards recyclable turbines. In the solar industry, recycling and circularity are especially well developed in companies such as Canadian Solar, Iberdrola, NextEra Energy and Orsted.

In September 2021, Vestas successfully completed its first US blade recycling project by decommissioning and recycling 10 turbine blades. The recycling methods included co-processing cement, gasification, forming new composite materials, and reclaiming glass fibre and carbon fibres. Vestas is open to offering such services outside the US in regions where local recycling infrastructure is robust and customer demand can be established (Vestas, 2021). Vattenfall claims that around 85-90 per cent of the total mass of a wind turbine, such as the foundation, tower and components in the nacelle, have established recycling practices, leaving the biggest challenge as the recycling of the composite material of blades. In 2021, Vattenfall made a commitment to an immediate landfill ban on decommissioned wind turbine blades and to actively work on increasing the recycling rate of wind blade components with the target of reaching 100 per cent recycling by 2030 at the latest (Vattenfall, 2021). Siemens Gamesa and RWE have made progress in developing a recyclable rotor blade, with Siemens Gamesa committing to offering a 100 per cent recyclable turbine by 2040 at the latest (Siemens Gamesa, 2021; RWE, 2021). Many of these commitments align with WindEurope's call for a European ban on landfilling rotor blades by 2025 (WindEurope, 2021). In the US, GE has also been making progress in developing recyclable blades (GE, 2021a). Collaboration and stakeholder engagement have been the key for several companies to advance innovation in recycling and circularity such as with WindEurope, Spanish Wind Energy Association, DecomBlades Consortium, Salzgitter AG, ZEBRA Consortium and even start-ups such as Thermal Recycling of Composites (TRC) (Siemens Gamesa, 2021; Vestas, 2021; Orsted, 2022, GE, 2021a; EDPR, 2021).

Such developments may not be as widespread within the solar industry although there are a few noteworthy advancements. Orsted has made commitments to reuse or recycle all solar PV modules that break or retire during installation, operation or decommissioning at their solar farms in Region Americas (Orsted, 2022). NextEra Energy has also made similar commitments to reuse and recycle solar infrastructure components (NextEra Energy, 2022). There is also evidence of collaboration, as can be seen in the case of Canadian Solar partnering with Reclaim PV Recycling for solar module end-of-life management activities in Australia. Canadian Solar also works closely with recycling service providers such as PV Cycle and Rinovasol Group to ensure full compliance with all legal Waste for Electric and Electronic Equipment (WEEE) obligations and that appropriate market import actions are followed (Canadian Solar, 2021). Iberdrola Ventures – PERSEO (a start-up programme) has been continuing the initiative launched in 2020 for investing in and creating circular economy businesses in recycling of photovoltaic modules (Iberdrola, 2021). What would be crucial for both industries is to support research into material recycling of composite waste and working with partners and within the industry to find new solutions for recycling and reuse.

APPENDIX 15: GOOD PRACTICES IN CARBON FOOTPRINT MANAGEMENT

LIFE CYCLE ASSESSMENT HARMONIZATION

Developer	NREL
Year published	n.d.
Description	In this project, NREL reviewed and harmonised life cycle assessments (LCAs) of electricity generation technologies to reduce uncertainty around estimated environmental impacts and increase the value of these assessments to the policymaking and research communities. Hundreds of life cycle assessments have been published, with considerable variability in results. These variations in approach hampered comparison across studies and the pooling of published results. NREL harmonised these data to: • Understand the range of published results of LCAs of electricity generation technologies • Reduce the variability in published results • Clarify the central tendency of published estimates
URL	https://www.nrel.gov/analysis/life cycle-assessment.html

A THREE-STEP APPROACH TO BEST PRACTICE LCA

Developer	EcoAct
Year published	2021
Description	One of the simplest best practice guidance for LCA is by Lau Tambjerg, an EcoAct senior consultant, who shares a three-step approach to best practice product LCA and demonstrates how it can help accelerate stakeholders on their path to net zero (Tambjerg, 2021): **1. Go deep:** Delve deeper into the facts for the best understanding and to achieve the greatest impact. This can involve tasks like comprehending and enhancing the accuracy of the underlying inventory data, obtaining data directly from certain suppliers rather than relying on secondary data and consulting with suppliers to find ways for them to cut emissions, etc. **2. Go wide:** Widen the scope of the evaluation to include several, if not all, of the products in the portfolio. Understanding portfolio-wide hotspots will make it possible to make strategic decisions that can change the entire product range or band. **3. Go again:** Set up governance to oversee and routinely review the products' assessments after step 1 and step 2 have been completed. This will make it possible to monitor emissions over time and ensure that relevant persons are knowledgeable about any contextual elements that might have an impact on the emissions (such as changing the electricity grid mix). To help present a continuous picture of emissions from products as well as the larger organization, use tools like EcoAct's Carbon reduction and feasibility tool (CRaFT).
URL	https://eco-act.com/life cycle-assessment/best-practice-lca/

INTERNATIONAL GOOD PRACTICE PRINCIPLES FOR SUSTAINABLE INFRASTRUCTURE

Developer	United Nations Environnent Programme (UNEP)
Year published	2022
Description	UNEP's *International good practice principles for sustainable infrastructure* (2022) provides "guidance for global use on the integration of sustainability throughout the entire infrastructure life cycle, with an upstream focus at the project level." Considering the guidance covers sustainable infrastructure in its entirety, the principles are highly relevant for the alternative energy sector. Although the guidance is specifically aimed at governments in creating an enabling environment for sustainable infrastructure, the guidance is universal because its focus on issues such as resource efficiency and circularity, equity, inclusiveness and empowerment is relevant to all stakeholders. The guidance describes 10 principles for infrastructure planning and development. The third of these principles focuses on a comprehensive LCA of sustainability covering a wide range of social and environmental risks, including carbon emissions.
URL	https://wedocs.unep.org/bitstream/handle/20.500.11822/34853/GPSI.pdf

GUIDELINES FOR AN INTEGRATED ENERGY STRATEGY

Developer	World Business Council for Sustainable Development (WBCSD)
Year published	n.d.
Description	The World Business Council for Sustainable Development (WBCSD) *Guidelines for an integrated energy strategy* sets out how to achieve a company's energy-related financial and environmental objectives, considering all energy uses within its operations and across its energy-related value chain. An integrated energy strategy has four crucial objectives: • Engaging with workforce and value chain partners to improve energy efficiency • Using smart controls to improve energy and fuel efficiency • Upgrading and replacing equipment and assets to improve energy efficiency • Collaborating with suppliers, customers and employees The guidelines highlight the benefits of an integrated energy strategy, which includes reducing life cycle GHG emissions and improving circularity, along with reducing life cycle air and water quality impacts (WBCSD, 2019).
URL	https://wbcsdpublications.org/integrated-energy-strategy/

WHOLE LIFE CARBON ASSESSMENT FOR THE BUILT ENVIRONMENT

Developer	Royal Institution of Chartered Surveyors
Year published	2023

Description	In accordance with EN 15978 (the British Standard Institute's assessment of the environmental performance of a building, based on LCA), *The whole life carbon assessment for the built environment* (2017) by the Royal Institution of Chartered Surveyors (RICS) is a professional statement that offers a consistent and transparent whole-life carbon assessment implementation plan and reporting structure for built projects. The statement also makes it possible for whole-life carbon assessment outputs to be coherent, which enhances the results' comparability and usability. Other goals of the declarations include advancing the circular economy, making LCAs more widely used and improving LCA reliability. Despite being nonspecific, the statement is relevant for on-site renewable building instalments (Sturgis & Papakosta, 2017).
URL	https://www.rics.org/content/dam/ricsglobal/documents/standards/whole_life_carbon_assessment_for_the_built_environment_1st_edition_rics.pdf

PRODUCT ENVIRONMENTAL FOOTPRINT (PEF)

Developer	European Commission, Joint Research Centre and Institute for Environment and Sustainability
Year published	2012
Description	*Product environmental footprint (PEF) guide* by Manfredi et al. (2012) from the European Commission, Joint Research Centre and Institute for Environment and Sustainability: provides guidance on how to calculate a PEF, as well as how to develop product category-specific methodological requirements for use in PEF category rules. The PEF is a multi-criteria
URL	https://ec.europa.eu/environment/eussd/pdf/footprint/PEF%20methodology%20final%20draft.pdf

INTERNATIONAL REFERENCE LIFE CYCLE DATA SYSTEM (ILCD)

Developer	Joint Research Centre
Year published	2012
Description	*The International reference life cycle data system (ILCD) handbook* by Wolf et al. (2012) from the Joint Research Centre: specifies the broader provisions of the ISO 14040 and 14044 standards on environmental LCAs. To summarise, it provides a basis for consistent, robust and quality-assured environmental LCA studies, as required in a policy and market context.
URL	https://publications.jrc.ec.europa.eu/repository/handle/JRC58190

METHODOLOGY GUIDELINES ON LIFE CYCLE ASSESSMENT OF PHOTOVOLTAIC ELECTRICITY

Developer	IEA Photovoltaic Power Systems Programme (PVPS)
Year published	2011

Description	*Methodology guidelines on life cycle assessment of photovoltaic electricity* by Fthenakis et al. (2011) from IEA Photovoltaic Power Systems Programme (PVPS): provides guidance on PV-specific parameters used as inputs in LCA and on choices and assumptions in life cycle inventory data analysis and on implementation of modelling approaches.
URL	https://iea-pvps.org/wp-content/uploads/2020/01/Task_12_-_Methodology_Guidelines_on_Life_Cycle_Assessment_of_Photovoltaic_Electricity_3rd_Edition.pdf

IMPLEMENTATION OF LIFE CYCLE IMPACT ASSESSMENT METHODS

Developer	Ecoinvent Centre
Year published	2010
Description	*Implementation of life cycle impact assessment methods* by Hischier et al. (2010) from Ecoinvent centre: offers life cycle inventory and LCIA results. There is a range of methodological problems and questions while linking the LCIA methods with the elementary flows of a database. This leads to variable results, even if the same LCIA method was applied to the same inventory results. The aim of this report is to avoid such discrepancies.
URL	https://ecoinvent.org/wp-content/uploads/2020/08/201007_hischier_weidema_implementation_of_lcia_methods.pdf

SOLAR SUSTAINABILITY: BEST PRACTICES BENCHMARK

Developer	SolarPower Europe
Year published	2022
Description	*Solar Sustainability: Best Practices Benchmark* by SolarPower Europe (2022) aims to identify state-of-the-art sustainability practices in the solar PV industry and showcase them as benchmarks, to support the whole PV sector's sustainability performance and to drive overall sustainable change. This guidance addresses a range of risks related to solar energy including carbon footprint.(Other issues are already addressed in the Supply Chain Section.) The approaches and best practices to reduce Solar PV carbon emissions as suggested by the guidance are as follows: 1. Consume as little energy as possible in the manufacturing process 2. Use low carbon electricity in the manufacturing process 3. Minimise the use of carbon-intensive materials 4. Minimise emissions from transportation 5. Prioritise PV system locations with the the highest emission reduction potentials 6. Maximise recycled content 7. Extend product lifetime and increase energy yield 8. Consider carbon emissions from non-module components The study also highlights case studies to reduce carbon emissions.
URL	https://www.solarpowereurope.org/insights/thematic-reports/solar-sustainability-best-practices-benchmark

RESPONSIBLESTEEL INTERNATIONAL STANDARD (VERSION 2.0)

Developer	Responsible Steel
Year published	2022
Description	*ResponsibleSteel International Standard (Version 2.0)* by Responsible Steel (2022): The objective of the ResponsibleSteel Standard is to support the responsible sourcing and production of steel as a tool for the achievement of ResponsibleSteel's vision: to maximise steel's contribution to a sustainable society. The Standard consists of thirteen principles for the responsible sourcing and production of steel with Principle 10 referring to Climate Change and Greenhouse Gas Emissions. In order to achieve its objective, the standard aims to: • Define the fundamental elements that characterise the responsible sourcing and production of steel to the satisfaction of downstream customers, users and civil society supporters. • Define levels of performance in the implementation of these fundamental elements that: - Encourage the broad participation of steelmakers in both developed and developing countries in the ResponsibleSteel programme - Merit the recognition and endorsement of the programme's civil society supporters - Maximise steel's contribution to a sustainable society through the responsible sourcing of its raw materials and management of the impacts of its production.
URL	https://www.responsiblesteel.org/wp-content/uploads/2022/09/ResponsibleSteel-Standard-2.0.pdf

GCCA SUSTAINABILITY GUIDELINES FOR THE MONITORING AND REPORTING OF CO_2 EMISSIONS FROM CEMENT MANUFACTURING

Developer	Global Cement and Concrete Association
Year published	2019
Description	*GCCA Sustainability Guidelines for the monitoring and reporting of CO_2 emissions from cement manufacturing* (Global Cement and Concrete Association, 2019): Considering that the carbon footprint of concrete is dominated by the production of cement, and the major GHG associated with cement is CO_2, the GCCA has released these guidelines for monitoring and reporting CO_2 emissions of cement production, also covering energy consumption as one of the key drivers for CO_2 emissions in the sector. These guidelines give an introduction to the monitoring and reporting process, specify applicable protocols, and deliver the Key Performance Indicators (KPIs) that are considered most relevant for the cement industry. The KPIs can also be used by companies for benchmarking their performance.
URL	https://gccassociation.org/wp-content/uploads/2019/10/GCCA_Guidelines_CO2Emissions_v04_AMEND.pdf

Part three: Recommendations

APPENDIX 16: POTENTIAL STAKEHOLDER COLLABORATORS

Ipieca would benefit from collaborating with the following stakeholders:

ORGANIZATION (NOTE: ORANGE REFERS TO SOLAR, GREEN REFERS TO WIND, AND BLACK REFERS TO BOTH)	RISKS ADDRESSED (SOURCING)	LIFE CYCLE STAGE
BRE National Solar Centre (NSC)	Biodiversity Risks, Land Use Risks	Operation
Copper8	Solid Waste/Hazardous Solid Waste	End of Life
Electric Power Research Institute (EPRI)	Solid Waste/Hazardous Solid Waste	End of Life
G+ IOER	Air Pollution	Operation
Global Reporting Initiative (GRI)	Child Labour, Forced Labour	Sourcing
ICMM	Human Rights Violations, Labour/ Community Health and Safety, Biodiversity Risks	Sourcing
Initiative for Responsible Mining Assurance (IRMA)	Child Labour, Labour/Community Health and Safety, Forced Labour, Air Pollution, Water Stress/Contamination, Waste, Biodiversity Risks	Sourcing
Institute of Acoustics (IOA)	Turbine Noise	Operation
International Energy Agency (IEA)	Solid Waste/Hazardous Solid Waste	End of Life
International Renewable Energy Agency (IRENA)	Solid Waste/Hazardous Solid Waste	End of Life
International Union for Conservation of Nature (IUCN)	Construction Noise, Biodiversity Risks, Water Stress/Contamination	Manufacturing & Construction

ORGANIZATION (NOTE: ORANGE REFERS TO SOLAR, GREEN REFERS TO WIND, AND BLACK REFERS TO BOTH)	RISKS ADDRESSED (SOURCING)	LIFE CYCLE STAGE
IUCN	Collision, displacement and habitat changes (birds and bats), Biodiversity Risks, Water Stress/Contamination	Operation
Mining Shared Value	Human Rights Violations, Corruption, Child Labour, Forced Labour	Sourcing
National Renewable Energy Laboratory (NREL)	Solid Waste/Hazardous Solid Waste	End of Life
NatureScot	Air Pollution, Water Stress/ Contamination, Biodiversity Risks	Manufacturing & Construction
NatureScot	Air Pollution, Water Stress/ Contamination, Biodiversity Risks	Operation
OECD	Human Rights Violations, Conflicts, Child labour, Displacement of Indigenous Communities	Sourcing
Responsible Cobalt Initiative (RCI)	Human Rights Violations, Conflicts, Corruption	Sourcing
Responsible Minerals Initiative (RMI)	Human Rights Violations, Conflicts, Corruption	Sourcing
Solar and Storage Industries Institute (SSII)	Biodiversity Risks, Land Use Risks	Manufacturing & Construction
Solar and Storage Industries Institute (SSII)	Biodiversity Risks, Land Use Risks	Operation
Solar Energy Industries Association (SEIA)	Human Rights Violations, Labour/ Community Health and Safety Risks, Forced Labour, Air Pollution, Water Stress/Contamination, Waste, Climate Change impacts	Sourcing

ORGANIZATION (NOTE: ORANGE REFERS TO SOLAR, GREEN REFERS TO WIND, AND BLACK REFERS TO BOTH)	RISKS ADDRESSED (SOURCING)	LIFE CYCLE STAGE
Solar Energy Industries Association (SEIA)	Human Rights Violations, Labour/Community Health and Safety Risks, Forced Labour, Air Pollution, Water Stress/Contamination, Waste, Climate Change impacts	Manufacturing & Construction
Solar Energy Industries Association (SEIA)	Human Rights Violations, Labour/Community Health and Safety Risks, Forced Labour, Air Pollution, Water Stress/Contamination, Waste, Climate Change impacts	Operational
Solar Energy UK	Biodiversity Risks	Operation
SolarPower Europe	Labour/Community Health and Safety Risks	Operation
The Copper Mark	Human Rights Violations	Sourcing
Towards Sustainable Mining (TSM) Initiative	Child Labour, Labour/Community Health and Safety, Forced Labour, Water Stress/Contamination, Climate Change Impacts, Biodiversity Risks, Displacement of Indigenous Communities	Sourcing
Wind Europe	Solid Waste/Hazardous Solid Waste	End of Life
World Bank Group	Water Stress/Contamination, Biodiversity Risks, Noise	Manufacturing & Construction
World Bank Group	Water Stress/Contamination, Biodiversity Risks, Turbines Noise	Operation
World Bank Group	Solid Waste/Hazardous Solid Waste, Water Stress/Contamination, Biodiversity Risks, Noise, Impacts on landscape and visual	End of Life

APPENDIX 17: POTENTIAL RENEWABLES COMPANIES COLLABORATORS

Algonquin, Brookfield Renewables, Canadian Solar, Constellation, EDP Renewables, GE, Hitachi Energy, Iberdrola, JinkoSolar, NextEra Energy, Orsted, RWE, Siemens Gamesa, SunPower, TPI, Vestas and Vattenfall. In terms of wind energy, companies such as Brookfield Renewables, EDPR, GE, Orsted, RWE, Siemens Gamesa, Vattenfall and Vestas are well-placed within the recycling and circularity industry. Canadian Solar, Iberdrola, NextEra Energy and Orsted could be the industry leaders with the respect to solar industry. There are also other companies and organizations that have made advancements within the recycling industry, and it would be worth collaborating with them.

APPENDIX 18: POTENTIAL COLLABORATORS FOR CARBON FOOTPRINT MANAGEMENT FOR WIND AND SOLAR

One of the most advanced solutions is the development of green steel by the Swedish Companies Hybrit and H2. Wind energy companies such as Brookfield Renewables, EDPR, GE, Orsted, RWE, Siemens Gamesa, Vattenfall and Vestas are well placed within the recycling and circularity industry. Canadian Solar, Iberdrola, NextEra Energy and Orsted could be the industry leaders with the respect to solar industry. There are also other companies and organizations that have made advancements within the recycling industry, and it would be worth collaborating with them as well.

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Ipieca is the global oil and gas association dedicated to advancing environmental and social performance across the energy transition. It brings together members and stakeholders to lead in integrating sustainability by advancing climate action, environmental responsibility and social performance across oil, gas and renewables activities.

Ipieca was founded at the request of the United Nations Environment Programme in 1974. Through its non-lobby and collaborative approach Ipieca remains the industry's principal channel of engagement with the UN.

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