Chapter 7

KEY ISSUES FOR SEA IN THE SOLAR POWER SUB-SECTOR

7.1 EXISTING SEA GUIDANCE/GUIDELINES FOR THE SOLAR POWER SUB-SECTOR

An international survey of existing SEA guidelines conducted for the IAIA was unable to identify any guidelines specifically focused on the solar power sub-sector.

The US Department of Energy provides guidance for preparing a solar programmatic environmental impact statement (PEIS) to assess environmental impacts associated with the development and implementation of agency-specific programmes that would facilitate environmentally responsible utility-scale solar energy development in six western states[1].

A number of guidelines and papers address project-level IA for wind power developments and for large-scale solar energy development proposals[2].

7.2 SOLAR POWER INSTALLED CAPACITY

In 2021, the world had in excess of 800GW of installed capacity. By far, China had the most capacity (c. 300 GW), followed by India, Spain, Brazil, Mexico and Chile (all <50 GW)[3]. Capacity by region is indicated in Table 7.1).

According to the International Energy Agency (IEA), solar is on track to set records for new global deployments each year after 2022, with an average of 125 GW of new capacity expected globally between 2021 and 2025[4].

Table 7.1: Installed solar power capacity by region, 2021
Source: https://ourworldindata.org

Region	Installed capacity (GW)
Africa	10.30
Asia	501.58
Australia	19.02
Europe	184.95
Middle East	7.97
North America	104.88
South & Central America	22.82
Oceania	19.07
World	843.09

The World Bank identifies photovoltaic potential by country, summarised in a global map (Figure 7.1).

[1] Arizona, California, Colorado, New Mexico, Nevada and Utah
[2] e.g. Bennun *et al*. (2021; NSW Government (2017)
[3] https://ourworldindata.org
[4] https://nsenergybusiness.com/features/climate/energy-policy-iea/

Figure 7.1: Photovoltaic power potential: a global picture

Figure redacted pending securing copyright permission to use. This is a World Bank map. If you have a map image showing this spatial distribution of photovoltaic power globally that you can provide (with permission to use – please indicate the credit to cite) we would be delighted if you can send it.

7.3 BACKGROUND TO SOLAR POWER GENERATION

Solar photovoltaic (PV) technologies convert sunlight directly into electricity using photovoltaic cells.

Concentrating solar power (CSP) technologies use a mirror configuration to concentrate the sun's light energy onto a receiver and convert it into heat. The heat can then be used to create steam to either drive a turbine to produce electrical power or it can be used directly as a source of power.

Solar PV generation can be installed on rooftops: integrated into building designs; or installed at utility scale on land (ground-mounted) and as "*floating" solar* (FPV) (with PV panels installed on platforms or membranes) on a body of fresh water or in a marine environment[5].

Solar generation is typically integrated with thermal or electrical energy storage systems (e.g., batteries, compressed air, or molten salt, which works as a medium to store solar thermal energy) that can provide power during cloudy periods or the hours of darkness. This ability to store solar energy makes solar power a flexible and dispatchable source (one that can be ramped up or shut down in a relatively short amount of time) of renewable energy. Large solar farms require a substation and connection to the electricity grid via a transmission line. Access roads are also often needed.

A solar farm requires much less maintenance during operation than other renewable energy sources, although the panels require periodic repair and cleaning. Solar cells and storage batteries have an operational lifespan of approximately 20–30 years. While panels and batteries can be recycled, the process is complex and costly, and they are often disposed to landfills. A solar farm can create large volumes of waste that are likely to be sent to landfills. The waste produced during the operation and decommissioning of CSP can more easily be recycled as the equipment and infrastructure do not involve complex manufactured parts like photovoltaic cells and storage batteries. However, CSPs do require significant quantities of thermal conducting fluid (e.g., conduction oil), which is likely to be an environmental hazard and more complex regarding its end-of-life use and disposal.

The mining of raw materials is required to produce the solar units, as well as the other equipment and infrastructure associated with a solar farm. This can result in significant environmental and social impacts given the activities and scale employed during the extraction and processing stages. Mineral extraction has direct impacts on sensitive areas if the minerals are located in such areas, e.g., impacts on biodiversity, air quality and land use, noise, overuse of water, waste generation, labour and human rights considerations. In general, a low-carbon future will be very mineral-intensive because clean energy technologies need more materials than fossil-fuel-based electricity generation technologies. Solar PV power is one of the most mineral-intensive forms of renewable energy. The manufacturing process can involve a number of hazardous materials, including acids and other compounds such as gallium arsenide—a key chemical that can absorb relatively more energy in some solar panels, which is toxic.

The majority of the solar projects to date have been ground-mounted with CSP technology. Floating PV is still considered a niche technology, but it is a growing industry with annual growth expected to be 20% per year until 2024[6]. FPV projects are being pursued in around 60 countries around the world[7], e.g. Da Mi project in Vietnam (Box).

[5] IFC (2012d)
[6] IRENA (2021b)
[7] IRENA (2021b).

Box 7.1: Da Mi floating solar energy project, Viet Nam

The Da Mi Reservoir is Viet Nam's first floating solar farm. The project was connected to the grid in 2019. The project has a total capacity of 47.5 MW peak and power output of about 70 million kilowatt-hours per year. It comprises 143,940 solar panels on 50 hectares of the reservoir in Tanh Linh and Ham Thuan Bac districts of Binh Thuan province, approximately 220 kilometers northeast of Ho Chi Minh City. The project life cycle is expected to be 25 years. In 2018, the Asian Development Bank approved a $17.6 million loan for the project.

Figure 7.2: Da Mi Floating Solar Energy Project, Viet Nam

Figure redacted pending securing copyright permission to use. If you have an image showing this project that you can provide (with permission to use – please indicate the credit to cite) we would be delighted if you can send it.

Source: Asian Development Bank (2018). Proposed Loan and Administration of Loans Da Nhim - Ham Thuan - Da Mi Hydro Power Joint Stock Company Floating Solar Energy Project (Viet Nam). Available at: https://www.adb.org/sites/default/files/project-documents/51327/51327-001-iee-en_9.pdf

Box 7.2 provides examples of other solar energy projects in Southeast Asia.

Box 7.2: Examples of solar energy projects in Southeast Asia

- The 240 megawatt (MW) B.Grimm Dau Tieng Solar Power Project occupying 270 ha of land in the Tay Ninh Province, Viet Nam. It started operation in 2019.
- The 73 MW Central Thailand Solar PV farm that has been in operation since 2012.
- The 60 MW Rooftop Solar PV project undertaken by Green Yellow Energy in Thailand. This project will see 92 Solar PV systems located on the premises of industrial buildings and facilities in Thailand.

Figure 7.3: Central Thailand PV: Solar Power Project - Thailand's First Solar Power Facility

Photo credit: Gerhard Joren/ADB

Sources:

Asian Development Bank. Thailand: Solar Power Project. https://www.adb.org/projects/43936-014/main Asian Development Bank; Asian Development Bank. Viet Nam: B.Grimm Viet Nam Solar Power Project (Dau Tieng Project). B.Grimm Viet Nam Solar Power Project (Dau Tieng Project): Environment and Social Compliance Audit Report | Asian Development Bank (adb.org);

Asian Development Bank. Viet Nam: Floating Solar Energy Project. Available at: https://www.adb.org/projects/51327-001/main; 43936-014: Solar Power Project (adb.org);

Asian Development Bank, Green Yellow Rooftop Solar Project, Thailand, 2021 available at: Green Yellow Rooftop Solar Project: FAST Report | Asian Development Bank (adb.org).

7.4 IMPACTS OF SOLAR ENERGY DEVELOPMENT

Table 7.2 summarises the key environmental and socio-concerns concerns likely to be associated with solar energy development.

Table 7.2: List of key environmental and socioeconomic issues for solar power

ISSUE	COMMENT
Environmental	
Land-use change	• Loss of productive land due to large extent of land required for developments (usually 1-2 ha per MW) • Displacement or destruction of existing livelihood activities and physical structures • Unlike wind, less opportunity for solar projects to share land with agricultural uses
Habitats and biodiversity	• Construction of access roads and transmission lines can result in land clearance and loss and/or fragmentation of habitat and present a collision and electrocution risk for bats and birds. • Increased access to remote areas that may increase hunting/poaching and introduction of invasive alien species • Habitat below solar panels may be altered due to shade conditions.
Soil erosion	• Construction on vast areas of land can result in soil compaction, alteration of drainage channels and increased erosion
Water use	• Increased water demand: for cooling central towers in concentrating solar thermal plants and cleaning of photovoltaic (PV) modules • This can be problem particularly in arid areas
Wastes (hazardous and non-hazardous)	• Broken or end-of-life solar panels (containing heavy metals) require recycling or disposal to landfill • Storage batteries contain hazardous substances and heavy metals and discharges can occur in the event of damage. Recycling potential for batteries varies across regions of the globe • Small scale spills of oils or other substances during construction, maintenance, and operation • Manufacturing process of PV cell includes several hazardous materials, most of which are used to clean and purify the semiconductor surface
Greenhouse gases	• Solar power can reduce GHG emissions where it displaces coal as a fuel source
Noise and vibration	• Noise and vibration caused by construction traffic and use of machinery
Air quality	• Soil disturbance and traffic on dirt roads creates dust • Dust generated during construction phase • Release of soil-carried pathogens and an increase in air particulate matter can contaminate water reservoirs
Water quality	• Potential river or groundwater contamination through leakage of potentially hazardous chemicals used in thermal conducting fluids, semiconductors, and storage batteries
Mineral extraction	• Overextraction of minerals used for solar PV panel and battery manufacturing
Visual and aesthetic impacts	• Solar PV reflection can damage sight and vision of community members • Solar infrastructure disrupt the aesthetic view and landscape of the host community
Socioeconomic	
Human rights issues	• Some mineral mining companies (which supply solar PV companies) are known to violate the rights of communities (e.g., rights to land, livelihood, ability to undertake traditional cultural practices) • Mineral mining companies are known to employ forced and child labor

ISSUE	COMMENT
	• Some solar companies accused of exploiting forced labour in manufacturing of solar panels and equipment
Local economy and livelihood	• Land acquisition may result in relocation of people and their structures • Increased pressure on the host communities' public services • Large amounts of land will be acquired and will displace the livelihood activities of affected communities (e.g., rice cultivation) • Loss of income from fishing activities, rice cultivation, and other farming activities • Loss of income from small business and enterprise activities due to people being displaced • Rural communities will lose access to grazing land (used on either a formal or informal basis) for cattle and livestock • Increase land value and property value within the vicinity of solar farms • Local communities can gain from benefit-sharing scheme with solar PV companies
Cultural heritage	• Loss of cultural, religious, historical and archaeological sites, and properties (e.g., when land appropriated for solar farms is destroyed or damaged due to transmission lines and access roads) • Limits on access to cultural heritage sites
Health and safety	• Inhalation of silicon dust during PV cell manufacture • High-voltage electricity transmission lines from the solar PV farm can cause safety issues for the communities during construction and operation (e.g., electric shocks from touching live cables) • Solar PV reflection cause glint and glare issues for communities
Gender and vulnerability	• Vulnerable groups (e.g., the poor, women, persons with disabilities, children, the elderly, and indigenous communities) may be disadvantaged and at particular risk • Employment opportunities within new projects • Opportunities for vulnerable groups to acquire new skills and learn new technologies (i.e., solar PV)
Access to water	• Increased demand on clean water • Limited communities' access to clean underground water (when extracted for cleaning panels)
Migration	• Leads to introduced diseases, inappropriate cultural behavior, etc. • Pressure on preexisting health services and infrastructure, equipment, human resources, essential drugs, etc. due to the project • Tension between immigrants and workers • Gender-based violence due to an influx of predominantly male construction workers
Public services and infrastructure	• Loss of, or relocation of, public services and infrastructure on land acquired for solar farms • Improvement to infrastructure, including roads and bridges, schools, health centers, and administrative buildings due to community investment by solar companies • Pressure on public services and infrastructure will increase as a result of immigration • Heavy vehicles and transportation damage existing roads and bridges • Increased vehicular traffic during construction

ISSUE	COMMENT
Employment and labour conditions	• Job opportunities may be provided to the local communities on solar farms (mainly during construction.) • Job opportunities generated from new investment in mineral extraction
Aviation	• Concentrating solar power systems in some circumstances could potentially cause interference with aircraft operations if reflected light beams become misdirected into aircraft pathways

7.3.1 Environmental issues and impacts

Land use change

Utility scale ground-mounted solar PV can require significant areas of land for development of an asset. A study conducted in the United States in 2013[8] found that:

- A large fixed tilt PV plant that generates 1 gigawatt-hour per year requires, on average, 2.8 acres (1.14 ha) for the solar panels. This means that a solar power plant that provides all the electricity for 1,000 homes would require 32 acres (12.9 ha) of land.
- Small single-axis PV systems require on average 2.9 acres (1.17 ha) per annual gigawatt-hour—or 3.8 acres (1.5 ha) when considering all unused area that falls inside the project boundary.
- Concentrating solar power plants require on average 2.7 acres (1.1 ha) for solar collectors and other equipment per annual gigawatt-hour; 3.5 acres (1.4 ha) for all land enclosed within the project boundary.

Solar parks require land for the panel arrays (e.g. Box 7.2).

Box 7.3: Land required for solar panel, Benban Project, Egypt

The 1,800 MW Benban solar park is one of the largest solar projects in the world. It covers 37 square kilometers and is in the Aswan Province in southern Egypt. This project was constructed to reduce Egypt's reliance on fossil fuels and to help the country meet their carbon reduction commitments made at the nationally determined contributions under the Paris Climate Agreement. The project is expected to reduce the nation's carbon dioxide output by around 2 million tons per year.

The solar park has PV panels that vary in size from 1,200 x 600 mm to 2,000 x 1,000 mm. The project acquired land for the control centre, water supply pipeline, transmission line and substations - three substations required 15,000 m^2, and a fourth substation will require an area of 50,000 m^2 for its transformers and switchgear.

Despite the solar park being built in a desert, the scale of the project could lead to many environmental and social impacts, many cumulative, e.g., significant volumes of construction traffic leading to road safety issues, the accumulation of construction wastes and issues regarding the discharge of wastewater on such a large development. The project also provides considerable employment opportunities for local people.

Figure 7.4: Benban Solar Park, Egypt

Figure redacted pending securing copyright permission to use. If you have an image showing this solar park that you can provide (with permission to use – please indicate the credit to cite) we would be delighted if you can send it.

Source: NS Energy. Benban solar park, Egypt, world's biggest solar photovoltaic.

Floating photovoltaic or FPV has the benefit of limiting terrestrial land-use change. but there will still be some land-take associated with transmission lines and other project components that need to be located on land. The majority of FPV projects to date have been installed on artificial water sources (e.g., reservoirs), but momentum is picking up for installation of FPV in the marine environment.

[8] Ong *et al*. (2013)

Rooftop-mounted solar PV has the benefit of making use of existing rooftop space and thus does not require additional land-take. However, rooftop solar systems are small in size compared to utility-scale solar ground-mounted applications.

Agricultural lands and grasslands are most often considered for solar farm sites as they generally have suitable topography and require minimal clearing. These lands may support the livelihoods of local communities and industries or may be important for biodiversity including rare and threatened species. However, certain areas should be avoided for the development of solar farms including native grassland ecosystems, ridge tops, riparian areas and watercourses, and known wildlife corridors within the footprint of a solar power project[9].

In addition to having a socioeconomic impact, the loss of agricultural land can result in a shortage in local and regional supplies of agricultural products[10] . In limited cases, portions of land developed for a solar farm can still be used to grow some food crops (offsetting the impact on crop production to some extent) but, once panels are installed, productive capacity of the land is generally limited to grazing.

The significance of land-use changes following the development of a solar farm depends on the value of the pre-existing land-use. The siting of a solar farm on land with high value for biodiversity or to society would amplify the negative impacts of the development. Mining of raw materials and manufacturing of the units and solar farm equipment and infrastructure will also result in land-use change impacts, as land will need to be cleared if mines are expanded or new ones developed.

Increased mining demands from the uptake of renewables and their required raw materials will have implications for land-use change. Such impacts are discussed further in the section on mineral extraction.

Habitats and biodiversity

The development of a solar farm (including associated transmission and access infrastructure) will often require the clearing of vegetation. This can cause the removal of habitat for flora and fauna and cause deaths and displacement to other nearby areas—during both the construction and operational phases of PV and CSP. Where new access roads pass through forested and ecologically sensitive areas, this can result in increased traffic and road kills and can enable increased human presence which can further disturb habitats and biodiversity[11].

There is limited evidence of bird deaths associated with the operation of solar farms, although it has been recorded more frequently at CSP sites than at PV power sites. Most deaths have been associated with collision with structures and transmission lines (including electrocution), with some incidences of incineration[12] . Additionally, there is anecdotal evidence that birds may mistake the flat surfaces of PV panels for water bodies and fly directly into them causing injury [13].

Solar utilities can also cause habitat degradation due to changes in hydrology and water availability and quality. Pollution by dust, noise, light, vibration, solids and liquid waste can pose some risks. Construction, decommissioning, and repowering (replacing old technology to optimize performance) can lead to dust, waste, noise and light pollution impacts, but there are few examples of this being a significant issue for solar developments [14]. Most solar power generation technologies do not discharge pollutants into the environment, although accidental release can occur (e.g., conduction fluid). The once-through cooling systems associated with some concentrated solar power projects require the discharge of heated water into a receiving water body. This can negatively impact on the biodiversity in the waterbody which will be unlikely to be able to tolerate warmer conditions.

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[9] http://www.albertapcf.org/rsu_docs/mir_pcf_factsheet_wind-solar_jun2018_v04b.pdf
[10] Farja and Maciejczak (2021)
[11] IUCN (2021)
[12] EC (2020)
[13] Horváth et al. (2009); Huso et al. (2016)
[14] Farmer (1993); McClure *et al*. (2013)

Where animal species are displaced (at a solar farm site or along access road and transmission line routes), this can increase pressure on food resources in the areas they relocate to and may displace and out-compete other animals and species. The introduction of alien species, carried to the site by vehicles, construction equipment and people, can also put pressure on sensitive ecosystems. The fragmentation of biodiverse habitats by solar farms, access roads, and transmission lines can lower the resilience of local populations of species by preventing their free movement and access to food resources. This can ultimately affect the ability of a species to thrive in an area.

The significance of impacts due to solar farm development will depend on the richness and abundance of existing biodiversity at the site and along access road and transmission line routes, including the presence of rare and threatened species. The development of multiple solar projects across a region would amplify the negative effects on habitats and biodiversity, potentially resulting in a significant cumulative loss, even if each individual development only causes limited impacts.

Soil erosion

Soil erosion can occur when land is cleared for a solar farm and for access roads and transmission lines, particularly when there is inappropriate drainage design, and the land is unsealed allowing water to flow on the land surface and wind to blow soil from exposed bare land.

Compaction of soil from construction activities (e.g., vehicle movements and civil works) can lead to reduced infiltration, increased runoff, decreased soil bioactivity and decreased soil organic matter[15]. Soil erosion can lead to sedimentation in nearby water courses and sensitive habitats and to a consequent decline in water quality and loss of biodiversity.

Water use

The water consumption of PV solar farms is highest during the manufacturing and recycling processes. Water intensive manufacturing processes include minerals processing, extraction, purification and chemical etching[16] . Significant amounts of water are also required in the manufacturing of batteries, particularly in the extraction of lithium, which requires 500,000 gallons of water per metric ton of lithium[17].

A solar farm can have a significant impact on water resources depending on its location, the availability of water, and the technology chosen. Water is required during operation to wash the panels to maintain generation efficiency. The amount of water required depends on the size of the solar farm and the ambient levels of airborne dust. Globally, the cleaning of solar panels is estimated to use more than 10 billion litres. However, new research is developing a waterless no-contact electrostatic repulsion system[18].

CSP, like all thermal electric plants, requires water for cooling. Water use depends on the plant design, plant location, and the type of cooling system. CSP plants that use wet-recirculating technology with cooling towers withdraw approximately 800 gallons of water per megawatt-hour of electricity produced[19]. An example of such a project includes the Qinghai Delingha Concentrated Solar Thermal Power Project in the PRC, which is expected to generate 199 GWh of electricity every year[20].

CSP plants with once-through cooling technology have higher levels of water withdrawal, but lower total water consumption (because water is not lost as steam). Dry-cooling technology can reduce water use at CSP plants by approximately 90%.[21] However, the trade-offs to these water savings are

[15] DEP (2017)
[16] Tawalbeha *et al*. (2021)
[17] IER (2020)
[18] https://news.mit.edu/2022/solar-panels-dust-magnets-0311
[19] Price (2009)
[20] Asian Development Bank. *China, People's Republic of: Qinghai Delingha Concentrated Solar Thermal Power Project*.
[21] Price (2009)

higher costs and lower efficiencies. In addition, dry-cooling technology is significantly less effective at temperatures above 100 degrees Fahrenheit .[22]

The demand for water can put pressure on existing local water supplies in areas where water resources are scarce, and in sensitive areas, particularly during dry seasons.

Wastes (hazardous and non-hazardous)

The PV cell manufacturing process includes hazardous materials, most of which are used to clean and purify the semiconductor surface. These chemicals include hydrochloric acid, sulfuric acid, nitric acid, hydrogen fluoride, 1,1,1-trichloroethane and acetone[23]. The amount and type of chemicals used depends on the type of cell, the amount of cleaning that is needed, and the size of silicon wafer. Incorrect management of the manufacturing process, including waste management, can lead to the release of hazardous and non-hazardous wastes into the environment.

Most waste generation at a solar farm will occur during the construction phase, with only limited wastes produced during operation from maintenance activities and ancillary activities (e.g., office wastes). Construction waste streams include:

- Material from packaging,
- Building materials,
- Scrap metals,
- Excess soil material,
- Plastic and masonry products,
- Vegetation clearing,
- Sanitary wastes,
- Empty chemical storage containers, and
- Concrete wash out water.

Solar cells and storage batteries have an operational lifespan of 20–30 years. Solar panels are mostly made of glass, which has low value as a recycled material. The panels also contain small amounts of valuable materials such as silicon, silver and copper, and heavy metals (cadmium, lead, etc.) that some governments classify as hazardous waste. While panels and batteries can be recycled, the process is complex and costly, and they are often disposed to landfills. Therefore, the decommissioning of a PV solar farm can create large volumes of waste that are likely to be sent to landfills where hazardous contents may leach out and pollute soil and groundwater. Countries are still expected to bolster their policy and regulatory frameworks around PV end-of-life management[24].

The waste produced during the operation and decommissioning of CSP plants can more easily be recycled as the equipment and infrastructure do not involve complex manufactured parts like photovoltaic cells and storage batteries. However, plants do require significant quantities of thermal conducting fluid (e.g., conduction oil) that is likely to be hazardous to the environment if not managed and disposed of correctly[25]***.***

Noise and vibration

Solar farms are generally located in areas of low population density which, in most instances, will limit the number of people impacted by noise and vibrations. Wildlife in the surrounding area may be displaced by noise and vibration and/or their behavioural patterns disturbed. The scope of such impacts will be significantly greater (and possibly temporary) during construction. Solar farms do not emit significant noises during operation.

[22] UCS (2013)
[23] UCS (2013)
[24] IEA (2016)
[25] Giaconia *et al*. (2021)

The development of a solar farm will require minor civil works involving heavy machinery followed by construction work by workers and using lifting equipment. The scale and significance of the impacts will depend on the size of the installations, the proximity of sensitive receivers and the duration of construction works. Solar farms are generally relatively quick to construct, therefore any construction impacts are temporary. The total time estimated to develop a utility scale 250 MW solar (from onset to commissioning) is about 6 years, including 4 years planning and development and 2 years for construction, testing and start-up[26].

Air quality

The construction phase of solar projects can generate dust due to clearing works, vehicle movements, earthworks, stockpiling, transporting materials, road works and concrete works. Exhaust emissions will be generated by construction and workers' vehicles and machinery during construction. Air quality impacts (pollution and dust) during the operation of solar plants will be limited to vehicle movements along access roads and over unsealed land and the aerosolization of dust caused by wind. The power generation process does not release pollutants into the air.

The severity of impacts on air quality will depend on the proximity of sensitive receivers (such as dwellings) to the solar farm site.

Water quality

Where solar farms and associated infrastructure (access roads and transmission lines) are located near to rivers and lakes, construction work (excavation and stockpiling of materials and spoil, and land clearing) can cause soil erosion and lead to sedimentation of such water bodies, impairing water quality and damaging aquatic habitats. The greater risk of sedimentation is from land clearing as the exposed areas will be subject to erosion by wind and surface water flows (particularly during intense tropical rainstorms).

Hazardous materials involved in construction can include paints, cleaning solvents and acids, concrete products, soil additives for stabilization and fuels. When used or stored improperly, these chemicals can escape from the construction site and have negative impacts on local water quality. The quantity of hazardous materials is expected to be small, so the scale of impacts will likely be localized.

The operation and management of a PV solar farm does not generally require large quantities of hazardous substances, and the potential for negative impacts on water quality is small. CSP projects use large volumes of thermal fluid, which can pollute a water course if accidentally released. Once-through CSP projects require the continuous discharge of heated water which, depending on the volume of the discharge and the size of the receiving water body, can have a significant negative impact on water quality. Discharges can also include antifouling chemicals.

The landscape design of a solar farm, extent of unsealed land and drainage strategy will influence the likelihood of sedimentation impacts on receiving waterbodies during operation because of windblown dust and surface water flows.

Mineral extraction

A low-carbon future will be very mineral-intensive because clean energy technologies require more materials than fossil-fuel-based electricity generation technologies. Solar PV power is one of the most mineral-intensive forms of renewable energy, alongside wind and geothermal. The associated infrastructure (e.g., transmission lines), battery storage solutions, and material parts needed to deliver a solar project, will further increase the need for minerals[27] to manufacture components. Current

[26] https://www.seia.org/research-resources/development-timeline-utility-scale-solar-power-plant
[27] Minerals in this context also include metals

projections suggest significant increases in mineral extraction will be required to keep up with the demands[28].

The solar PV industry will need to compete for resources with other clean energy technologies as many of the minerals required are crosscutting across technologies and uses. For example, copper is a key component in both solar and wind for the conduction and connection of electricity. Together, these renewable energy technologies constitute 74.2% of all demand for copper. Other minerals are more concentrated on a single technology. For example, lithium, graphite, and cobalt are mainly associated with energy storage solutions. The recycling and reuse of minerals will play a key role in reducing demand from mining but increased mined quantities will still be required to meet the future growth in the industry.

Mining for minerals and their processing for use in the solar power industry can result in significant environmental impacts given the activities and scale employed during the extraction and processing stages. The heterogenous distribution of minerals across the globe often means their extraction has direct impacts on sensitive areas if the minerals are in such areas.

The Democratic Republic of Congo is the world leader in cobalt production, accounting for more than 70% of global output in 2019. There have been several examples of dangerous occupational safety working conditions, human rights abuses including child labour, and environmental damage associated with Congolese cobalt – prompting many major companies who rely on the country's supply chains to form initiatives aimed at promoting higher ethical standards[29].

Key environmental impacts of mineral mining include:

- Biodiversity impacts, including habitat damage and loss, disturbance and killing of species, competition from alien species, and ecosystem disruption;
- Overuse of water supplies and impacts on water quality and groundwater;
- Waste generation and pollution;
- Reduced air quality for sensitive receivers;
- Noise and vibration (including from blasting) impacts on sensitive receivers;
- Land-use change;
- Landscape and visual amenity degradation;

With the increase in mineral extraction expected to support the expansion of solar power generation, the cumulative impacts environmental (and social – see section on human rights in 7.3.2) systems will continue to rise even if mitigation strategies are implemented.

Visual and aesthetic impacts

The visual impact of solar installations is an issue that is frequently raised by the public, local communities, and environmental activists. Depending on the degree of visual impact, public opinion can strongly oppose the installation of a solar farm and significantly hinder its implementation.

The significance of a visual impact during both operation and construction typically depends on the landscape character and topography of the local area, the size of the installation, the level of screening (trees, etc.) and the number of visual receivers within the zone of influence. As many solar installations are installed in rural areas, their influence on the landscape character can be significant. This is most acute with CSP installations which can involve tall tower structures.

There is a perception that PV solar panels cause glint and glare, which can distract motorists and aircraft and cause eye damage. Solar PV modules are specifically designed to reduce reflection to minimize loss of light and convert it to electricity. Research shows that PV modules exhibit less glare than windows and snow[30] . PV has been installed at airports in the US, including Denver and Oakland.

[28] World Bank (2020b)
[29] https://www.nsenergybusiness.com/features/top-cobalt-producing-countries/
[30] Reach Solar Energy (2018)

There is more risk of glint and glare from CSP projects because these use mirrors to concentrate the solar rays. This can pose a potential hazard or distraction for motorists, pilots, and pedestrians[31]. The design and location of a CSP is critical in avoiding this problem.

7.3.2 Socio-economic issues and impacts

Local economy and livelihoods

Similar to hydropower technology, the development of solar PV farms may induce large-scale land acquisition that results in economic and physical displacement of the host communities.

This displacement can cause adverse short- and long-term impacts on livelihood activities, affecting income from rice cultivation, small businesses, and enterprise activities of the host communities. Rural communities can also lose access to grazing land (used on either a formal or informal basis). In the case of floating solar PV, the acquisition of water space can impact access to fisheries and navigation.

Land acquisition for solar parks and substations can lead to physical and economic displacement that needs to be addressed through resettlement planning. The use of marginal land or land not in high demand for other uses is preferable (e. g., the Benban project in Egypt (Box) used desert land that was vacant). This means that highly productive land required for food supplies or land assigned for other important social purposes such as residential areas will not be affected.

Some solar PV park development projects can provide opportunities including benefit-sharing schemes between the host communities and the solar PV companies (see Boxes 7.4 and 7.7) and can lead to an increase in land and property values within the vicinity of the solar farm.

Box 7.4: Joint investment in a solar farm, Dorset, United Kingdom

In Dorset in the UK, local communities benefit from joint investment in solar PV farms, often through the local Parish or Town Council. The funding may be through an annual payment over the life of the solar farm or a one-off payment once the solar farm is first commissioned. Solar farm community benefit funds totalling around UK £2m over 20 years have now been offered to 12 Dorset communities.

Source: Dorset Council. Community Renewable Energy and community benefits - Dorset Council.

Employment and labour conditions

The construction of solar farms can create jobs for neighbouring communities and skilled workers. One review found that the construction of four large-scale solar farms in the US (each 250 MW) created the FTE jobs for between 405 and 830 workers per month for a project duration of 2 to 3.5 years[32] .The average annual workforce for operations and maintenance was estimated at 68 (10 general, six engineering, 25 maintenance, 22 operations and five unskilled) (footnote 32). By comparison, it was found that 500 FTE jobs were created for half a year to construct the 25 MW Permacity PV project.

While other countries may not reach the same efficiencies and require additional labour, this information helps to show that solar projects have generally short construction phases and small operational workforces.

Error! Reference source not found.IRENA reports that millions of jobs had already been created by solar PV projects by 2020 (Figure **7.5**7.5) with job opportunities having increased significantly compared to other technologies in the renewable energy sector.

[31] Ho and Kolb (2010)
[32] White *et al.* (2010)

While investing in solar PV power brings jobs to local communities, there is a need to manage associated operational health and safety risks.

Concerns regarding the extraction of mineral resources for manufacturing solar PV are discussed in the human rights section.

Figure 7.5: Number of Jobs in Each Renewable Sector and Solar Photovoltaic

Figure redacted pending securing copyright permission to use from IRENA. If you have an image showing this information in a bar chart from the years 2012 - 2020 that you can provide (with permission to use – please indicate the credit to cite) we would be delighted if you can send it.

Cultural heritage

Cultural, religious, and archaeological sites can be destroyed or access to them restricted when land is acquired for solar power farms. Box cites concerns raised in the media about the impacts of a Maltese solar farm on cultural and archaeological heritage.

Box 7.5: Impacts of solar farm on cultural heritage and archaeological sites in Malta

"The effects of a proposed solar farm on the rain catchment system near Ta' Ħaġrat archaeological site is of great concern for Heritage Malta. The national agency for cultural heritage said it feared the proposed solar farm in Triq San Pietru, Mġarr might negatively affect the site when heavy rainfall causes the road leading to the temples to flood. This is mainly a result of the vast development in Mġarr during the last 50 years. What is mainly worrying Heritage Malta is that the proposed project will prevent the rainwater from penetrating the soil, resulting in runoff flowing into the temples."

Source: www. newsbook.com.

Health and safety

The main such risks occur during the construction phase and typically include managing physical, chemical, and biological hazards[33]. In addition to working with live power lines, EMF, work on floating solar farms involves the additional risk of operating over and under water[34] . Weather conditions are a significant factor when working on outdoor solar photovoltaic installations and affects the risks to lives and working conditions.

Solar farms can have negative impacts on community health and safety, e.g., from electric shocks when facilities are unfenced, or cables not cased. Depending on the proximity of residential areas and other community activities, the impacts of exposure to glint (momentary flashes of light) and glare (continuous, excessive brightness) from solar PV reflection may need to be modeled and mitigation measures identified. Glint and glare can affect nearby residents, road users, airplane pilots and air traffic controllers[35].

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33 IFC (2012c)
34 World Bank, ESMAP and Solar Energy Research Institute of Singapore (2018)
35 DELWP (2022); SolarTech Advisor. 2021. Can Glare From Solar Panels Affect Aircrafts? | Solartechadvisor.

In some circumstances, CSP systems can cause interference with aircraft operations if reflected light beams become misdirected into aircraft pathways[36]. For instance, light reflection from CSP solar panels can distract pilots and air traffic controllers and interfere with airport equipment[37]. The adverse impacts on aircraft movements can be due to the proximity between the solar farm and their airports. Some airport companies oppose nearby solar farms. For example, Barrow/Walney Island Airport in the UK objected to a proposed solar farm, citing such concerns. Analysis of solar PV glare has been part of the impact assessment for the installation proposed at the Kuantan Airport in Malaysia.

As previously discussed, solar farms typically have small workforces and for short construction periods, so the influx of labour is not a substantial risk.

The impacts (positive and negative) of immigration induced by the development of solar farms are similar to those due to other types of renewable energy.

Gender and vulnerability

Where solar projects have negative impacts that affect livelihoods, women are often disproportionately affected. As solar farms increase in size, they may also impact on housing, health and social care services, and sociocultural quality of life (Box7.6).

Box 7.6: Gender and other impacts of the NOOR solar plant, Morocco

A study of the NOOR solar power plant development in Morocco, North Africa, showed that people living near the plant, especially women, reported decreased abilities to practice livelihood activities such as grazing goats and collecting firewood as construction ramped up. Families who did not profit from employment opportunities at the plant were left more vulnerable to economic shocks.

Construction of the NOOR plant led to an increase in migration to the area of external and foreign workers and students, which changed the social and cultural make-up of the community. It also contributed to an increased population with the potential to put a strain on public infrastructure and services like sanitation, healthcare, and education.

Source: Renewable and Sustainable Energy Reviews. 2019. Social impacts of large-scale solar thermal power plants: assessment results for the NOORO I power plant in Morocco. https://www.sciencedirect.com/science/article/abs/pii/S1364032119304678?via%3Dihub [Accessed 11/05/2022]

The underrepresentation of women in the solar energy sub-sector is another issue, and one that is also reflected across all technologies. In 2019, the IEA identified that a growing number of women are looking at the sub-sector as a source of well-paid employment with strong opportunities for career advancement. Because solar PV technology requires a workforce for installation, sales, and operations and maintenance, IEA suggested that there is a wide range of opportunities available for women[38].

Solar power projects can also create opportunities for benefit-sharing among wider community members, local government, and private investors (Box7.7) and for female-led business ventures (Box7.8).

[36] Solar Energy Development Programmatic EIS. Solar Energy Development Environmental Considerations (anl.gov)
[37] Solartechadvisor (2021)
[38] IRENA (2017)

Box 7.7: Benefit-sharing from solar farms in the United Kingdom

Lambeth Council Community Energy Programme was part of the UK's Community Energy Initiative to reduce, purchase, manage and generate energy through collective action. The programme was a successful collaborative partnership involving Repowering London (a community-based organization), Lambeth City Council and select private local investors to co-produce three community-owned PV solar projects with a total installed capacity of 132kW through community share offers. Training and work experience was also provided to local young people from some of the poorest social housing estates in the area.

Source: UK Department of Energy and Climate Change. 2014. Community Energy Strategy: Full Report. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/275169/20140126Community_Energy_Strategy.pdf

Box 7.8: A female-led solar power company in Thailand

The SPCG Public Company Limited in Thailand is a pioneer company in solar farms and solar roof development. It is headed by a woman. SPCG owns 36 PV solar farm projects that sell electricity to Thailand's distribution grid. The company's businesses, include engineering, procurement and construction for solar farms and solar rooftops, and it manufactures steel or metal roof sheets. In 2017, the company employed more than 1,000 people.

Source: https://www.iea.org/reports/seven-women-entrepreneurs-of-solar-energy

Indigenous communities

Solar energy projects require land or bodies of water that may customarily be owned or used by indigenous peoples. There is a risk of conflict between communities and project developers if the latter do not secure the free prior and informed consent (FPIC) to projects from indigenous communities[39]. FPIC is required by various multilateral development banks and other bodies[40]. This issue is addressed in the discussion of indigenous communities in Chapter 5 (hydropower).

There are examples from many countries where stand-alone solar power systems are used to provide electricity to indigenous communities, especially to remote and/or small communities[41] (Box 7.9).

[39] Free, Prior and Informed Consent (FPIC) is a specific right that pertains to indigenous peoples and is recognised in the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP). It allows them to give or withhold consent to a project that may affect them or their territories. Once they have given their consent, they can withdraw it at any stage. Furthermore, FPIC enables them to negotiate the conditions under which the project will be designed, implemented, monitored and evaluated. This is also embedded within the universal right to self-determination.

[40] e.g. by the IFC under its Performance Standard 7 guideline (IFC 2012b); and by the ADB's commitment to Broad Community Support (BCS) under its Safety Policy Statement (2009).

[41] Martire (2020)

Box 7.9: Examples of solar projects serving indigenous communities

Canada

There are opportunities for indigenous peoples in Canada to own or co-own the solar projects on their lands. The largest off-grid solar project in Canada (2.2 MW) is located at Fort Chipewyan. It was projected to cost CDN$4.5 million, create 40 jobs during construction, and replace 650,000 litres of diesel fuel per year, reducing greenhouse gas emissions by 1,743 tons annually. The indigenous people in this area benefit from job opportunities during the construction and from cleaner electricity generated.

Figure 7.6: Ft. Chipewyan Solar Farm

Figure redacted pending securing copyright permission to use. If you have an image showing this solar farm that you can provide (with permission to use – please indicate the credit to cite) we would be delighted if you can send it.

Source: Solar Energy Moves Indigenous Communities Toward a Renewable Future (Canada) in a news release, August 2019. Solar Energy Moves Indigenous Communities Toward a Renewable Future - Canada.ca; Indigenous Business Australia, provided in Powering Indigenous communities with renewables – Renew.

Western Australia

Indigenous Business Australia (a government body) is a co-equity investor with an indigenous Noongar (an Aboriginal people in Western Australia) community partner, Bookitja in a 10 MW solar farm at Northam.

Figure 7.6: Northam Solar Farm in Western Australia

Figure redacted pending securing copyright permission to use. If you have an image showing this solar farm that you can provide (with permission to use – please indicate the credit to cite) we would be delighted if you can send it.

Access to water

During its operational phase, a solar project will require water to wash PV solar panels and maintain their efficiency, or to cool concentrating solar power plants. This may be accessed from underground or surface water and may decrease supplies of clean water available to the local community, particularly in dry areas.

Public services and infrastructure

Solar farm projects can have negative impacts on public services and infrastructure. The movement of heavy goods vehicles and the transportation of materials and can damage existing roads and bridges and increase traffic congestion in the host communities.

But solar farms may also benefit local communities through investment programs to support local economic development, improve local infrastructure and services, and support social programs to improve community well-being (Box7.10). This can be done by project community investment programs as outlined by IFC's community investment handbook[42].

Box 7.10: Solar company support for community services, India

In India, Avaada (a company renewable energy company) supports a number of interventions near its solar project sites to improve health outcomes for host communities, including no-cost medical services. Specialized and general awareness camps and regular health check-ups are provided to raise awareness and help local residents lead healthier lives. In addition, Avaada is addressing sanitation challenges in rural India by building toilets and clean drinking water facilities in underserved communities.

Source: Avaada Energy. Sustainability. http://www.avaadaenergy.com/sustainability.html; International Finance Corporation. LargeScaleWindSolar.

Human rights

Solar photovoltaic panels require minerals that are mined in various countries, including in low-income and conflict-affected countries where human rights are not well regulated or enforced. Key social impacts of mineral mining include:

- Child and forced labour (see Box 7.11);
- Forced resettlement, land take and violence;
- Occupational health and safety including physical and mental health.

[42] IFC (2010)

Box 7.11: Use of forced labour in the People's Republic of China

Recently, there has been a focus on the Uyghur Region in the People's Republic of China—a major producer of solar panels. In 2021, United Kingdom (UK) academic researchers found that the region accounted for approximately 45% of the world's solar-grade polysilicon supply. The study identified 11 companies engaged in forced labour transfer, plus another four located in industrial parks, and 90 Chinese and international companies whose supply chains were affected.

In a related article in 2021, *The Guardian* newspaper reported that solar projects commissioned by the Ministry of Defence, the government's Coal Authority, United Utilities and some of the UK's biggest renewable energy developers were using panels made by Chinese solar companies accused of exploiting forced labour camps in Xinjiang province in the People's Republic of China. The newspaper article suggested that up to 40% of the UK's solar farms had panels manufactured by solar panel companies that use interned Muslim Uyghur community members in polysilicon production. Acknowledging this risk, the World Bank has recently issued guidance on measures to avoid forced labour through solar projects.

Sources:

Murphy and Elimä (2021)
The Guardian. 2021. Revealed: UK solar projects using panels from firms linked to Xinjiang forced labour. 25 April. Revealed: UK solar projects using panels from firms linked to Xinjiang forced labour | Solar power | The Guardian;
IPF Solar Procurement Bidder Declaration - Forced Labor
https://thedocs.worldbank.org/en/doc/a5d4a4a88227973aecdbab19dd58258e-0290032021/original/Forced-Labor-Solar-Declarations-and-provisions-for-Procurement-Documents-ext.docx

TIPS

To add