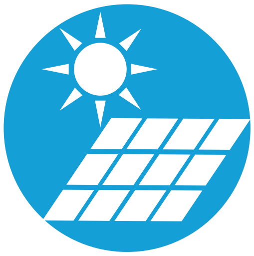
IMPROVING DECISION-MAKING FOR THE ENERGY TRANSITION

Guidance for using Strategic Environmental Assessment

CHAPTER 7

SOLAR POWER



Compiled by:
Barry Dalal-Clayton
Miles Scott-Brown

July 2024
Updated October 2024

Version 1

IAIA
International Association for Impact Assessment

Links to the complete guidance document and to individual chapters are also available.

CHAPTER 7

SOLAR POWER

7.1 WHY SEA IS IMPORTANT TO SOLAR POWER

An overall rationale for why it is important to use strategic environmental assessment (SEA) to support the energy transition is provided in the preface to the guidance.

SEA can provide critical information to support better decision-making for solar power planning and development, including identifying where there may be implications for policies, plans, and programs (PPPs) to adequately address significant environmental and/or socioeconomic risks and impacts. This information can be particularly important to identify and assess the scale and significance of possible cumulative impacts of multiple solar power schemes/developments whether alone or in combination with other renewable energy technologies (e.g., wind energy).

The SEA process will:

- Identify and focus on key environmental and socioeconomic issues and the concerns of likely affected stakeholders, including local communities, vulnerable groups, and indigenous peoples. Major issues are discussed in detail in Section 7.5 and are summarized in Table 7.2.
- Identify/recommend if there are areas that should be avoided for solar power development ("no-go" areas) because of particularly high risk to the environment, habitats/biodiversity, and/or people/communities.
- Identify what changes or additions are required to PPPs governing solar power development to address these risks.
- Make subsequent project-level Environmental Impact Assessments (EIAs) and Environmental and Social Impact Assessments (ESIAs) more efficient and cheaper by addressing the big picture regarding potential upstream, downstream, and cumulative impacts and identifying the particular issues that individual solar power project EIAs/ESIAs should focus on in more detail. This may also include spatial planning recommendations for optimal siting of solar power projects to minimize these risks and impacts. Such project-level EIAs/ESIAs should identify/recommend mitigation measures to avoid, minimize/reduce negative impacts, compensate, offset, and restore/rehabilitate land at the end of a project, as well as to enhance positive impacts and benefits.
- Engage stakeholders who may be affected by solar power developments (particularly in areas where solar power potential has been identified) to be informed early of proposed or possible policy options or plans, and enable them to provide their perspectives and present their concerns. This will enable key issues to be identified and verified, help build understanding and support for solar development, and avoid future misunderstanding and possible conflicts.

The steps and methodologies available for use in SEA are common to all SEAs, whatever they are focused on, and reflect internationally accepted standards of good practice. They are discussed in detail in Chapters 1 and 2 and are therefore not repeated in this chapter.

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

An international survey of existing SEA guidelines conducted for 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 programmatic environmental impact statement (PEIS) to assess environmental impacts associated with the development and implementation of agency-specific programs that would facilitate environmentally responsible utility-scale solar energy development in six western states.[1 2]

A number of guidelines and papers address project-level IA for solar power developments and for large-scale solar energy development proposals.[3]

7.3 SOLAR POWER INSTALLED CAPACITY

In 2022, the world had in excess of 1,053 gigawatts (GW) of installed capacity. By far China had the most capacity (393 GW), followed by India (63 GW), Brazil, Spain, Mexico, and Chile (all <20 GW each).[4] 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 125 GW of new capacity expected globally between 2021 and 2025.[5]

Table 7.1: Installed solar power capacity by region, 2021
Source: Our World in Data (2023)

Region	Installed capacity (GW)
Africa	12
Asia	620
Australia	27
Europe	230
Middle East	13
North America	130
South America	33
Oceania	27
Central America & Caribbean	4
World	1,053

Note: The regional totals cannot be summed to derive the World total as parts of some regions (e.g. Oceania) may already have been counted as parts of other regions.

7.4 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, which either drives a turbine to produce electrical power or is used directly as a source of power.

Solar PV generation can be:

- Installed on rooftops (distributed solar).
- Integrated into building designs (such as solar parking lots).
- Installed at utility-scale on land (ground-mounted), including on agricultural land (Agri-PV).
- Installed as floating solar (FPV) with PV panels installed on platforms or membranes on a body of fresh water or in a marine environment.[6]

FPV is still considered a niche technology, but it is a growing industry. According to IRENA (2021b), annual growth is expected to be 20% per year until 2024. Market data collected by Solar Power Europe (2023) indicates that total cumulative capacity reached 5.7 GW on a global scale in 2022—a

[1] Arizona, California, Colorado, New Mexico, Nevada and Utah.
[2] For more information, see "Why the Solar PEIS Is Needed" (https://solareis.anl.gov/eis/why/index.cfm).
[3] e.g., Bennun *et al*. (2021) and NSW Government (2017).
[4] Our World in Data (2023)
[5] NSEnergy (2021)
[6] IFC (2012d)

68% increase relative to 2021. FPV projects are being pursued in around 60 countries around the world[7], such as the Da Mi project in Vietnam (see Box 7.1).

Box 7.1: Da Mi floating solar energy project, Vietnam
Source: ADB (2018)

The Da Mi Reservoir is Vietnam's first floating solar farm. The project was connected to the grid in 2019. The project has a total capacity of 47.5 megawatts (MW) peak and power generation of about 70 million kilowatt-hours per year. It comprises 143,940 solar panels on 50 hectares of the reservoir in the 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 (ADB) approved a $17.6 million loan for the project.

Figure 7.1: Da Mi Floating Solar Energy Project, Vietnam

Photo: Courtesy of ADB

Solar generation can be integrated with thermal or electrical energy storage systems (e.g., batteries, compressed air, green hydrogen, 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 and vegetation between PV arrays may need to be cut/trimmed. Solar cells and storage batteries have an operational lifespan of approximately 20–30 years.

Recycling of PV panels

A solar farm can create large volumes of waste. While panels and batteries can be recycled, the process is complex, costly, and not yet fully established in many countries, so they are often disposed of in landfills. However, in Europe, significant steps have been taken to regulate recycling (see Box

[7] IRENA (2021a)

7.2). There are compulsory takeback schemes in certain US states, and a number of PV module producer companies also offer takeback schemes.[8]

Box 7.2: Recycling of PV panels
Source: EC (2024)

In Europe, recycling of PV waste was incorporated into the European Union's Waste Electrical and Electronic Equipment (WEEE) Directive in 2012. The Directive established that at least 85% of end-of-life waste must be collected and, from that, 80% must be reused and recycled. The EU Ecodesign rules for PV—expected to be adopted in Q4/2024—will significantly affect the availability of spare parts, the repairability of inverters, and improve the overall sustainability performance and reliability of PV products.

PV modules are currently recycled in existing facilities designed for glass or metal materials, although a few dedicated PV recycling plants have emerged in recent time. Glass and aluminum (materials that comprise 90% of the module´s weight) are typically recovered. The plastic component goes through energy incineration, harnessing energy.

There are several materials, including silver, zinc, tellurium, indium, and gallium, which make up only a small percentage of the module's total weight but hold significant value. Recovery of these materials is the true challenge. Methods are being developed to recover these materials. With an increasing waste stream likely to be produced from PV in the coming years, the recovery of materials of small weight will become more cost-effective, allowing improved purity of existing recovered materials.

Recycling of batteries in the EU is prescribed by the EU Regulation 2023/1542.[9]

As discussed in Section 7.5.1, the waste produced during the operation and decommissioning of CSP can more easily be recycled. The significant quantities of thermal conducting fluid required is a potential hazard and requires disposal.

Materials in solar panels

The two main types of PV technology are crystalline silicon and thin film.

Crystalline silicon modules account for 95% of installed capacity.[10] Production of these modules notably requires silicon, silver, and plastic materials. Small amounts of other materials, such as lead, nickel, zinc, boron, antimony, and germanium are needed (dependent on the concrete module subtype).

The main thin film module types include CdTe (CadmiumTelluride), CIGS (copper-indium-gallium-diselenide-disulphide), and amorphous silicon. CdTe modules are composed of 80-85% glass (by weight); the rest of the composition can contain aluminum, copper, antimony, cadmium, tellurium, and other minerals.[11] CIGS and amorphous silicon are considered niche markets, and their share of global demand is very small at present.

The manufacturing process can involve a number of hazardous materials, including acids and other compounds. Thin film module type CIGS contains gallium arsenide—a key chemical that can absorb relatively more energy in some solar panels—which is toxic.

[8] For more information, see the SEIA National PV Recycling Program (https://www.seia.org/initiatives/seia-national-pv-recycling-program).
[9] See europa.eu for the full regulation details.
[10] Bobba *et al.* (2020)
[11] IEA (2022e)

Examples of solar projects

Box 7.3 provides examples of other solar energy projects in Southeast Asia.

Box 7.3: Examples of solar energy projects in Southeast Asia
Sources: ADB (2013, 2021, 2023, 2023b)

The 240-MW B.Grimm Dau Tieng Solar Power Project occupying 270 hectares of land in the Tay Ninh Province of Vietnam started operation in 2019.

The 73-MW Central Thailand Solar PV farm has been in operation since 2012 (see Figure 7.2).

The 60-MW Rooftop Solar PV project undertaken by Green Yellow Energy in Thailand will see 92 Solar PV systems located on the premises of industrial buildings and facilities.

Figure 7.2: Central Thailand PV: Solar Power Project - Thailand's First Solar Power Facility

Photo: Courtesy of Gerhard Joren/ADB

Another form of solar power generation is through solar evaporation ponds (see Box 7.4).

Box 7.4: Solar evaporation ponds
Sources: Kuchta (2023), BTL Liners (n.d.)

A solar evaporation pond is a saltwater pool that can be used to produce and store thermal energy. Such saltwater ponds form a natural vertical “salinity gradient,” known as a halocline. In these ponds, the bottom is lined with salts, as much as a few meters deep, which are then heated naturally by the sun. Because the salts are heavier than water, they remain at the bottom of the pond, while the cooler top layer of water acts as an insulator of the heat generated below. As long as the upper layer of water remains clear and free of salt, sunlight can penetrate to the bottom of the pond. Solar rays heat the water at the bottom of the pool, making it less dense than the water above it, and a process known as convection occurs naturally.

Salt is added to solar ponds to saturate the lower, warmer water which can reach temperatures up to 900°C. The upper layers of low-salinity water, with much lower ambient temperatures, do not mix readily with the hot, high-salinity water, which is then pumped out to be used in a turbine to generate electricity or as a source of cost-effective thermal energy. The process is relatively simple and has been highly effective in generating electricity in rural areas of developing countries.

Generating electricity from rooftop panels (distributed system) has greater flexibility in size and location than utility-scale systems. However, while rooftop solar can supplement utility-scale solar, it cannot replace it. Nevertheless, rooftop solar provides greater resilience when considering potential hazards to the distribution system related to climate change, such as fires, icing events, or strong wind. Decision makers will need to consider whether utility or distributed scale systems are the right choice in particular locations, or what mix of these two is appropriate. The collective benefits associated with distributed systems may outweigh the impacts and risks of utility-scale power generation.

Over one-third of new solar PV capacity installations worldwide are rooftop attachments. The share of rooftop solar reached a peak in 2018, when 43% of all solar panels deployed that year were fitted on residential and commercial buildings. In Europe, this share is significantly larger, where rooftop solar accounted for 66% of both cumulative and annual installations in 2023.[12] China and the United States are expected to account for the greatest rooftop solar capacity additions in the next few years.[13]

7.5 IMPACTS OF SOLAR ENERGY DEVELOPMENT

During scoping for an SEA, key issues regarding solar power development should be identified. They will be used to focus the SEA on the most important issues and to help develop environmental and social quality objectives (ESQOs) (see Chapter 2, Section 2.5.1), which address these issues and will be used during the main assessment stage. The key issues will be identified by reviewing relevant documents (e.g., EIA and special subject reports, environmental/social profiles, sector and inter-sector strategies, donor documents, academic papers, other solar power development applications, solar irradiation profiles, meteorological data, etc.), interviewing key informants, and holding stakeholder consultations at national to local levels. Many of the issues will be well known as a result of implementing existing solar power development projects.

At the individual project level, these issues will be the focus of an EIA, which should recommend how to manage, avoid, or minimize/reduce potential negative impacts, compensate and offset for them, and restore/rehabilitate land at the end of a project, as well as enhance positive impacts and benefits. This guidance does not aim to present detailed options or opportunities for project-level mitigation, as they are often project-specific. Defining such options is a function of project-level EIAs.

While solar power, like other renewable energy technologies, has the potential to give rise to negative impacts (as indicated in Table 7.2), the replacement of coal and other fossil fuels by solar power and other renewable energy technologies will have the overall effect of reducing many of the negative impacts associated with fossil fuels, particularly those relating to carbon dioxide (CO_2) emissions.

Ideally, before individual solar projects are approved, an SEA of a policy, plan, or program (PPP) for the solar power sub-sector should be completed. This will involve the assessment of multiple projects, schemes, and activities: some directly concerned with the construction and operation of sites and facilities; others linked to associated infrastructure (e.g., transmission lines, access roads). Thus, there is a risk that the impacts of individual solar power developments/projects may become highly significant as they become cumulative. An SEA should focus on the potential for such cumulative impacts and make recommendations for addressing them. This may include recommending thresholds for particular factors that should not be breached by an individual project (and which should be addressed by a project-level EIA). Where the risks of cumulative impacts are extremely high, this might provide the basis for the SEA report to recommend an alternative to the PPP or components of it. Often, the timing of individual solar power applications and overarching SEA planning is not synchronized, and SEA may have to “catch-up” to the pace of individual projects rather than providing upstream (pre-project) guidance as to how they should proceed.

[12] SolarPower Europe (2023)
[13] Fernández (2023)

Table 7.2 summarizes the range of possible environmental and socioeconomic issues likely to be associated with solar energy development. In the planning and design of a solar power facility, all these issues should be addressed (particularly during project-level EIA) and measures identified and incorporated to avoid, minimize, mitigate, compensate, and offset them and to restore land when the project ends. In general, mitigation measures are not discussed in this section.

During scoping, a key task is to determine which issues the SEA should focus on.

Table 7.2: Environmental and socioeconomic issues for solar power

ISSUE	COMMENT
Environmental	
Air quality	• Soil disturbance and traffic on dirt roads create dust. • Dust is generated during the construction phase. • Release of soil-carried pathogens and an increase in air particulate matter can contaminate water reservoirs.
Greenhouse gases	• Solar power can reduce GHG emissions where it displaces coal or other fossil fuels as a fuel source.
Noise and vibration	• Noise and vibration are caused by construction traffic and the use of machinery.
Soil erosion	• Construction on vast areas of land can result in soil compaction, alteration of drainage channels, and increased erosion. • Solar panels can contribute to limiting soil erosion (e.g., on degraded land) and improving soil health.
Water use	• Increased water demand for cooling central towers in concentrating solar thermal plants (CSP) and cleaning of photovoltaic (PV) modules can be problematic, particularly in arid areas. • Agri-PV can achieve water savings by installing water collection systems and reusing water for irrigation purposes. • Water usage can be reduced as a result of panel shading.
Water quality	• Potential river or groundwater contamination can happen through leakage of potentially hazardous chemicals used in thermal conducting fluids, semiconductors, and storage batteries.
Land-use change	• Large areas required for developments (usually 1-2 hectares per MW) can mean a loss of productive land, although the land actually occupied by panels and their supporting structures is much smaller than the total solar farm area.[14] • Agri-PV can potentially increase land use productivity by combining energy generation and agricultural production.[15] • Earth movements may be required for site levelling. • Displacement or destruction of existing livelihood activities and physical structures is possible.
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 may increase hunting/poaching and introduce invasive alien species. • Associated infrastructure, particularly transmission lines, can result in collision and electrocution. • Habitat below solar panels may be altered due to shade conditions. • Panel shading at agri-PV sites can: protect crops and animals from adverse weather impacts like droughts, direct sunlight, and hail; increase crop yields—up to 60% increase has been recorded in Europe; and improve soil moisture retention, especially in dry regions. [6] • Well-designed and managed solar (PV) farms can increase biodiversity.[16] • Concentrated solar power beams can cause incineration.

[14] The proportion of land occupied by solar PV structures is typically 2.5%. See Bonadio J., Popa A., and Weiskopf V. (2021).
[15] Livestock such as sheep can graze amongst the PV arrays. For more information, see SolarPower Europe's Agrisolar Best Practice Guidelines (https://www.solarpowereurope.org/insights/thematic-reports/agrisolar-best-practice-guidelines-version-2-2) and Fraunhofer Institute for Solar Energy's Agrivoltaics Guidelines (https://www.ise.fraunhofer.de/en/publications/studies/agrivoltaics-opportunities-for-agriculture-and-the-energy-transition.html).
[16] For specific examples, see Helapco's 2016 study "The effects of solar farms on local biodiversity" (https://helapco.gr/wp-content/uploads/Solar_Farms_Biodiversity_Study.pdf), Solar Energy UK's 2019 report "The Natural Capital Value of Solar" (https://solarenergyuk.org/resource/natural-capital/), and BNE's 2020 study "Solar parks – profits for biodiversity" (https://www.bne-online.de/study-solar-parks-profits-for-biodiversity/).

ISSUE	COMMENT
	• Solar plants typically have security perimeter fencing installed, which can cause additional habitat fragmentation, especially for mammals and reptiles (e.g., tortoises), and act as a barrier to movement/migration.
Wastes (hazardous and non-hazardous)	• Broken or end-of-life solar panels containing heavy metals require recycling or disposal to landfills. • Storage batteries contain hazardous substances and heavy metals, and discharges can occur in the event of damage. • The recycling potential for batteries varies across regions of the globe. • Small-scale spills of oils or other substances during construction, maintenance, and operation are possible. • The manufacturing process of PV cells includes several hazardous materials, most of which are used to clean and purify the semiconductor surface. However, the spilling risks are limited.
Mineral extraction	• Over-extraction of minerals used for solar PV panel and battery manufacturing is possible.
Visual and aesthetic impacts	• Solar PV reflection can damage the sight and vision of community members. • Solar infrastructure disrupts the aesthetic view and landscape of the host community.
Land and ecosystem restoration	• Most current solar panels are designed to last for more than 25 years, after which land restoration will be required unless negotiations with landowners result in agreements to repower or upgrade the equipment and extend the solar farm's operational lifespan.
Socioeconomic	
Human rights issues	• Some mineral mining companies (which supply solar PV companies) are reported to violate the rights of communities (e.g., rights to land, livelihood, and ability to undertake traditional cultural practices). • Mineral mining companies are reported to employ forced and child labor. • Some solar companies are accused of exploiting forced labor in the manufacturing of solar panels and equipment.
Local economy and livelihood	• Land acquisition may result in relocation of people and their structures. • New development can increase pressure on the host communities' public services. • Large amounts of land will be acquired, displacing the livelihood activities of affected communities (e.g., rice cultivation). • Displacement can lead to a loss of income from fishing activities, rice cultivation, and other farming activities and from small business and enterprise activities. • Rural communities may lose access to grazing land (used on either a formal or informal basis) for cattle and livestock. • Land and property values often increase within the vicinity of solar farms. • Local communities can gain from benefit-sharing schemes with solar PV companies. • Local access to low-cost electricity can stimulate the local economy and livelihood opportunities.
Employment and labor conditions	• Job opportunities may be provided to the local communities on solar farms (mainly during construction). • Job opportunities may be generated from new investment in mineral extraction.
Cultural heritage	• A 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) is possible. • Limits on access to cultural heritage sites are possible.
Health and safety	• Inhalation of silicon dust during PV cell manufacture can cause health issues. • 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 can cause glint and glare issues for communities.

ISSUE	COMMENT
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. • New projects can provide employment opportunities and opportunities for vulnerable groups to acquire new skills and learn new technologies (e.g., solar PV).
Access to water	• Increased demand on clean water. • Communities may experience limited access to clean underground water (i.e., when water is extracted for cleaning panels).
Migration	• New workforce may lead to introduced diseases, inappropriate cultural behavior, etc. • Workforce migration may put pressure on pre-existing health services, infrastructure, equipment, human resources, essential drugs, etc. • Tension between immigrants and workers is possible. • Gender-based violence may increase due to an influx of predominantly male construction workers.
Public services and infrastructure	• Loss or relocation of public services and infrastructure on land acquired for solar farms may be required. • Improvement to infrastructure, including roads and bridges, schools, health centers, and administrative buildings, may occur with community investment by solar companies. • Pressure on public services and infrastructure can increase as a result of immigration. • Heavy vehicles and transportation can damage existing roads and bridges. • Increased vehicular traffic during construction is possible.
Aviation	• In some circumstances, concentrating solar power systems could potentially cause interference with aircraft operations if reflected light beams become misdirected into aircraft pathways.

Note: Some of the above-mentioned construction impacts would apply to multiple renewable energy projects, not just solar.

7.5.1 Environmental issues and impacts

Land use change

Utility-scale, ground-mounted solar PV can require significant areas of land for development of an asset. However, the proportion of solar farmland actually occupied by PV panels and their supporting structures remains limited—about 2.5% of total solar farmland.[17] The amount of land required to satisfy electricity demand in the EU in 2021 remained limited—only 0.26% of all the land in the EU.[18]

A study conducted in the United States in 2013[19] found that:

- A large, fixed-tilt PV plant that generates 1 gigawatt-hour per year requires, on average, 2.8 acres (1.14 hectares) 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 hectares) of land.

- Small, single-axis PV systems require, on average, 2.9 acres (1.17 hectares) per annual gigawatt-hour, or 3.8 acres (1.5 hectares) when considering all unused area that falls inside the project boundary.

- Concentrating solar power plants require, on average, 2.7 acres (1.1 hectares) for solar collectors and other equipment per annual gigawatt-hour, or 3.5 acres (1.4 hectares) for all land enclosed within the project boundary.

Solar parks require land for the panel arrays (see Box 7.3).

Box 7.5: Land required for solar panel, Benban Project, Egypt
Source: NS Energy (2018)

The 1,800 MW Benban solar park is one of the largest solar projects in the world. It covers 37 km^2 in Aswan Province in southern Egypt. This project was constructed to reduce Egypt's reliance on fossil fuels and to help the country meet its carbon reduction commitments made as 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 center, 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.

Floating PV 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. Combining floating PV with other energy-generating projects (e.g., floating PV in combination with hydropower dams, wind, etc.) can minimize the need for additional grid infrastructure and instead

[17] Bonadio *et al*. (2021).
[18] SolarPower Europe (2022). Note: Assumes 2021 values for EU power demand (i.e. not accounting for future electricity demand increase) and assuming 50% of solar capacity is installed on rooftops and 50% on land
[19] Ong *et al*. (2013)

utilize the existing one.[20] The majority of floating PV projects to date have been installed on artificial water sources (e.g., reservoirs), but momentum is picking up for installation of floating PV in the marine environment.

Rooftop-mounted solar PV has the benefit of making use of existing roof space and thus does not require additional land-take. While rooftop solar systems are small in size compared to utility-scale solar ground-mounted applications, they still account for the majority of installed capacity in the EU, with 65.9% in 2023 cumulative installations and 66% annual installations in 2023.

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 in rural areas 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, protected areas, and known wildlife corridors within the footprint of a solar power project.[21]

In addition to having a socioeconomic impact, the loss of agricultural land can result in a shortage of local and regional supplies of agricultural products.[22] On the other hand, there is also considerable potential to combine solar farms with agriculture. There are many potential benefits, from using water associated with cleaning panels for agriculture, to solar panels providing shade, and to panels providing mitigation from extreme rain events and limiting soil erosion. A number of agri-PV projects have shown an increase in crop yields, water efficiency, land efficiency, and overall improvements of social and economic aspects of the farms.[23] There is also emerging use of semi-transparent panels that have the potential to improve integration with agriculture.[24] Furthermore, there are good examples of solar farms sharing the land with other uses, such as sheep and fish farming.

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.

Increased mining of raw materials needed for the manufacture of solar PVs will have implications for land-use change, as well. 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 mortality and displacement to other nearby areas during both the construction and operational phases of PV and CSP projects. However, well-designed and managed solar farms can avoid impacts on biodiversity. For example, opportunities for local fauna and flora can be improved by designing the solar farm layout and managing activities around the solar farm to avoid habitats such as nesting and egg laying areas, foraging areas, wintering areas, hedgerows, field margins, meadows, and pollinator habitats. In the case of intensively-managed agricultural areas or degraded areas, restoration as a solar farm offers a significant opportunity.

A recent study showed that 9 out of 10 solar sites resulted in an increase of 14-281% biodiversity net gain. Similar studies showed a significant increase in local flora and fauna, i.e., the presence of endangered insect and butterfly species and other species at risk of extinction, or an increase in reptile and breeding bird population on solar sites.[25]

---

[20] SolarPower Europe (n.d.)
[21] Alberta Prairie Conservation Forum (2018)
[22] Farja and Maciejczak (2021)
[23] SolarPower Europe (2023c)
[24] For more information, see the 2022 article by S. Hall for the World Economic Forum (https://www.weforum.org/agenda/2022/07/agrivoltaic-farming-solar-energy/).
[25] See Helapco's 2016 study "The effects of solar farms on local biodiversity" (https://helapco.gr/wp-content/uploads/Solar_Farms_Biodiversity_Study.pdf), Solar Energy UK's 2019 report "The Natural Capital Value of Solar" (https://solarenergyuk.org/resource/natural-capital/), and BNE's 2020 study "Solar parks – profits for biodiversity" (https://www.bne-online.de/study-solar-parks-profits-for-biodiversity/).

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.[26] Solar farms typically have security perimeter fencing installed, which can cause additional habitat fragmentation, especially for mammals and reptiles (e.g., tortoises), and act as a barrier to movement/migration. However, well-designed solar parks can incorporate permeable fences so that mammals and smaller animals can pass through.

There is limited evidence of bird deaths associated with the operation of solar farms, although it has been recorded more frequently at CSP sites (particularly incineration in concentrated solar power beams) than at PV power sites. Most deaths have been associated with collision with structures and transmission lines (including electrocution), with some incidences of incineration.[27] Additionally, there is some anecdotal evidence that birds may mistake the flat surfaces of floating PV panels for water bodies and fly directly into them causing injury.[28]

Solar utilities can also cause habitat degradation due to changes in hydrology, as well as water availability and quality. If care in operation is not taken, pollution by dust, noise, light, vibration, and solid and liquid waste can pose some risks.

Construction, decommissioning, and repowering (i.e., 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.[29] 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 CSP projects require the discharge of heated water into a receiving water body. This can negatively impact the biodiversity in the waterbody, which may be unable to tolerate warmer conditions.

Where animal species are displaced (i.e., 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 PV array steel structures provide ideal nesting sites for some species of birds. This, in turn, attracts bird predators, such as snakes and other fauna that feed on bird eggs.[30]

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.

Solar evaporation ponds present a risk to wildlife, livestock, and habitats (e.g., drowning, poisoning, and overflow and contamination of natural waterbodies).

Soil erosion

Soil erosion can occur when land is cleared for a solar farm, access roads, and transmission lines, particularly when there is inappropriate drainage design (i.e., the land is unsealed, allowing water to flow on the land surface and wind to blow soil from exposed bare land). An important consideration for erosion prevention and storm water management is the dripline of the PV arrays, which tends to concentrate water runoff from the panels.

[26] Bennun et al. (2021)
[27] EC (2020)
[28] Horváth et al. (2009); Huso et al. (2016)
[29] Farmer (1993); McClure et al. (2013)
[30] SolarPower Europe (2022)

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.[31] 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.

Well-managed, biodiversity-friendly solar farms can help to improve soil health (e.g., switching from the use of pesticides to seasonal grazing, and integrating different restoration measures for degraded soils). Solar panels can help increase carbon stored in soil (by up to 80% where sheep management is integrated with the solar farm[32]), improve soil health, and enhance biodiversity on solar farm sites, which can, in turn, reduce soil erosion.

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.[33] 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.[34]

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 liters (2.64 billion gallons). However, new research is developing a waterless, no-contact, electrostatic repulsion system.[35]

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.[36] An example of such a project is the Qinghai Delingha Concentrated Solar Thermal Power Project in the People's Republic of China, which is expected to generate 199 GWh of electricity every year.[37]

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%.[38] However, the trade-offs to these water savings are higher costs and lower efficiencies. In addition, dry-cooling technology is significantly less effective at temperatures above 100^0F.[39]

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. In arid areas, agri-PV has been reported to reduce water use on the site by as much as 20-30% (especially during long periods of drought or high temperatures)[40] by panel shading and reducing evapotranspiration. Also, incorporating rainwater collection systems in the design of solar farms and reusing water for different purposes such as irrigation or cleaning of panels can improve the efficiency of water use.

---

31 DEP (2017)
32 Towner *et al.* (2022); For additional information, see BNE's 2020 study "Solar parks – profits for biodiversity" (https://www.bne-online.de/study-solar-parks-profits-for-biodiversity/).
33 Tawalbeha *et al.* (2021)
34 IER (2020)
35 MIT News (2022)
36 Price (2009)
37 ADB (2022)
38 Price (2009)
39 UCS (2013)
40 SolarPower Europe (2023c)

Where solar panels are installed to cover canals and reservoirs, a secondary benefit is that they keep water cooler and limit evaporation. Floating PV has been shown to reduce evaporation by up to 70%, and also to reduce algal growth.[41]

Additional water savings are possible through installing rainwater collection systems in APV sites.

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.[42] The amount and type of chemicals used depends on the type of cell, the amount of cleaning that is needed, and the size of the 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 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
- 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, copper, and tellurium, plus heavy metals (cadmium, lead, etc.) that some governments classify as hazardous waste. In modern PV panel manufacturing facilities, electro deposition and chemical deposition of cadmium is about 90% efficient, and no more than 0.0005% of the cadmium and tellurium used would be lost in the form of very dilute liquid and waste streams.[43]

Panels and batteries can be recycled. However, without a proper policy framework and sufficient economies of scale, the process can be complex and costly. In jurisdictions without an appropriate end-of-life management framework and extended producer responsibility schemes, these products are often disposed 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.[44]

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.[45]

A new technology for producing flexible and printable solar cells from perovskite offers a cheaper alternative to the use of silicon cells and could revolutionize the future of solar cell deployment.

[41] SolarPower Europe (2023b)
[42] UCS (2013)
[43] Bonadio *et al.* (2021)
[44] IEA (2016)
[45] Giaconia *et al*. (2021)

However, the technology is not yet developed commercially, and challenges remain regarding cell longevity and the use of lead in production.[46]

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 vibration. Wildlife in the surrounding area may be displaced by noise and vibration and/or have their behavioural patterns disturbed. The scope of such impacts will be significantly greater (and possibly temporary) during construction. Solar farms do not emit significant noise nor vibration during operation.

The development of a solar farm will require civil works involving heavy machinery, followed by construction using workers and lifting equipment. The scale and significance of the impacts will depend on the size of the installations, the flatness of the site, 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 Solar Energy Industries Association in the USA reports that, from initial application to final Right-of-Way grant, the current process for a utility-scale solar project requires between three and five years to complete.[47]

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 (e.g., 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 (e.g., access roads and transmission lines) are located near to rivers and lakes, construction work (e.g., 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 comes from land clearing, as the exposed areas will be subject to erosion by wind and surface water flows, particularly during intense 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 and temperature. Discharges can also include antifouling chemicals.

[46] Bellini (2024).
[47] SEIA (n.d.).

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 increase the need for minerals[48] to manufacture clean energy components to support clean energy technologies. The associated infrastructure (e.g., transmission lines), battery storage solutions, and material parts needed to deliver solar projects are also dependent on increased extraction of some minerals.[49] However, a clean energy grid will be significantly less extractive than the current fossil fuel dominated energy system. The amount of minerals needed for future energy systems represents a small fraction of the amount of materials—mainly fossil fuels—consumed by the current energy system. The amount of copper currently in use for the energy system is 21 million tons per year, plus 2.6 million tons of nickel and 0.11 million tons of lithium. As a comparison, current fossil consumption requires around 8 billion tons of coal, 4 billion tons of oil, and 2.6 billion tons of gas annually.[50] Additionally, coal, oil, and gas are combusted to produce energy and cannot be reused, whereas the minerals used in renewable energy infrastructure can be recovered, recycled, and reused.

The solar PV industry will need to compete for resources with other clean energy technologies, as many of the minerals required are cross-cutting 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 (e.g., impacts on biodiversity, air quality, land use, noise, water usage, waste generation, population, health, labor, and human rights). 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.

The Democratic Republic of Congo is the world leader in cobalt production, which is used for battery production required for energy storage, 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 labor, and environmental damage associated with Congolese cobalt. This has prompted many major companies who rely on the country's supply chains to form initiatives aimed at promoting higher ethical standards.[51]

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.

[48] Minerals in this context also include metals.
[49] World Bank (2020b)
[50] REN21 (2023)
[51] NS Energy (2021)

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

As mentioned previously, the use of Perovskite-Organic Hybrid Solar Cells sourced from common materials such as lead, iodine, and organic materials offers a lower-cost and less extractive-intense alternative to silicon cells.

Visual and aesthetic impacts

The visual impact of solar installations is an issue that is frequently raised by the public, local communities, and specialist interest groups. 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 (e.g., trees), 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. Practices like planting trees around the solar plants can help to reduce the visual impacts and better integrate solar farms into local landscapes.

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.[52] PV modules have been installed at airports in the United States, including Denver and Oakland.

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.[53] The design and location of a CSP is critical in avoiding this problem.

Land and ecosystem restoration

As discussed above, there are significant risks associated with solar power development with regard to potential environmental harm and degradation (e.g., unnecessary or excessive deforestation when preparing land for solar farms and constructing new access roads and transmission lines; destruction of habitats; loss of biodiversity and ecosystem services; soil erosion; and pollution). This will particularly arise where mitigation measures proposed by an SEA (and subsequent project-level EIAs) are inadequate, ineffective, or not undertaken. The significance and seriousness of such degradation can be compounded where the impacts are cumulative and extensive. Such cumulative impacts will be highly likely to occur where there are multiple solar farm developments across landscapes.

From a positive perspective, in general, solar farms constructed on degraded land should enable vegetation and soil carbon to regenerate and at least some local biodiversity to re-establish in areas from which it had previously been lost.

Environmental impacts will usually lead to demand for and need for land and ecosystem restoration (see Chapter 2, Box 2.12). This need will also arise at sites of projects that have come to the end of their useful operational life, usually after 20–30 years.[54] After this time, the project owner will either decommission the site, restore the area to its previous land use, or negotiate with landowners to repower or upgrade the equipment to extend the wind farm's operational lifespan.

[52] Reach Solar Energy (2018)
[53] Ho and Kolb (2010)
[54] The average lifespan of solar panels is about 25 years.

At a minimum, land/ecological restoration after decommissioning a solar farm should involve the seeding/replanting of disturbed areas. A seed mix of species that were naturally part of the ecosystem/land prior to development of the solar farm should be used.

7.5.2 Socioeconomic issues and impacts

Local economy and livelihoods

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 crop 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 used desert land that was vacant—see Box 7.5). This means that highly productive agricultural 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 7.6 and 7.9), and can lead to an increase in land and property values within the vicinity of the solar farm.

Box 7.6: Joint investment in a solar farm, Dorset, United Kingdom

Source: Dorset Council (n.d.)

In Dorset, United Kingdom, 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 totaling around UK £2m over 20 years have now been offered to twelve Dorset communities. Find more information about Dorset Council's "Low Carbon Dorset" grants and see these community case studies at https://www.lowcarbondorset.org.uk/.

Employment and labor conditions

The construction of solar farms can create jobs for neighboring communities and skilled workers. One review found that the construction of four large-scale solar farms in the US (each 250 MW) created full-time equivalent (FTE) jobs for between 405 and 830 workers per month for a project duration of 2 to 3.5 years.[55] The average annual workforce for operations and maintenance was estimated at 68 (10 general, six engineering, 25 maintenance, 22 operations, and five unskilled). [56] 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 thus require additional labor, this information helps to show that solar projects have generally short construction phases and small operational workforces. Thus, it can be seen that the difference in job creation between construction and operation should be planned to avoid large scale retrenchment after the close of construction as found in other industries, such as hydropower.

[55] White *et al.* (2010)
[56] CEERT (2010)

IRENA (2022) reports that millions of jobs had already been created by solar PV projects by 2020, with job opportunities having increased significantly compared to other technologies in the renewable energy sector.

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.

Cultural heritage

Cultural, religious, and archaeological sites can be destroyed or have access to them be restricted when land is acquired for solar power farms. Box 7.7 cites concerns raised in the media about the impacts of a Maltese solar farm on cultural and archaeological heritage. Measures need to be put in place to manage chance finds during construction, as per other industries that cause site disturbance.

Some cultural heritage features (e.g., historic buildings and graves) can be incorporated into the layout design of a solar farm and protected during construction.[57]

Box 7.7: Impacts of solar farm on cultural heritage and archaeological sites in Malta
Source: Camilleri (2021)

This excerpt is from an article by M.P. Camilleri (2021) in Newsbook 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."

Health and safety

The main risks to worker health and safety occur during the construction phase and typically include managing physical, chemical, and biological hazards, particularly dust generated during land clearing and grubbing out vegetation. In addition to working with live power lines and electric and magnetic fields (EMF), work on floating solar farms involves the additional risk of operating over and under water.[58] Weather conditions are a significant factor when working on outdoor solar PV installations and affect the risks to lives and working conditions.

Solar farms can also have negative impacts on community health and safety, such as 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 reflections may need to be modeled, and mitigation measures identified. Glint and glare can affect nearby residents, road users, airplane pilots, and air traffic controllers.[59]

[57] For more information and examples, see: Roberts, R. (2015, July 18). Listed churches all over England are installing solar panels. The Independent. https://www.independent.co.uk/news/uk/home-news/listed-churches-all-over-england-are-installing-solar-panels-10399129.html
[58] World Bank, ESMAP and Solar Energy Research Institute of Singapore (2018)
[59] DELWP (2022); SolarTechAdvisor (2023)

In some circumstances, CSP systems can cause interference with aircraft operations if reflected light beams become misdirected into aircraft pathways.[60] For instance, light reflection from CSP panels can distract pilots and air traffic controllers and interfere with airport equipment.[61] The adverse impacts on aircraft movements can be due to the proximity between the solar farm and an airport. 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 an installation proposed at the Kuantan Airport in Malaysia.

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

The impacts—positive and negative—of in-migration induced by the development of solar farms are similar to those that arise for 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 housing, health and social care services, and sociocultural quality of life (see Box 7.8).

Box 7.8: Gender and other impacts of the NOOR solar plant, Morocco

Source: Terrapon-Pfaff et.al. (2019)

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.

The under-representation 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 recognizing that the sub-sector is a source of well-paid employment with strong opportunities for career advancement. Because solar PV technology requires a workforce for installation, sales, operations, and maintenance, IEA suggested that there is a wide range of opportunities available for women.[62] The share of women working in full-time positions in the solar PV industry is 40%. This is almost double the share in the wind industry (21%) and the oil and gas sector (22%). The solar PV industry also compares well with the 32% share across the entire renewable energy landscape.[63]

Solar power projects can also create opportunities for benefit-sharing among wider community members, local government, and private investors (see Box 7.9) and for female-led business ventures (see Box 7.10).

[60] Solar Energy Development Programmatic EIS Information Center (n.d.)
[61] SolarTechAdvisor (2023)
[62] IRENA (2017)
[63] IRENA (2022c)

Box 7.9: Benefit-sharing from solar farms in the United Kingdom
Source: UK Department of Energy and Climate Change (2014)

Lambeth Council Community Energy Program was part of the UK's Community Energy Initiative to reduce, purchase, manage, and generate energy through collective action. The program was a successful, collaborative partnership involving Repowering London (a community-based organization), Lambeth City Council, and select private local investors. They co-produced 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.

Box 7.10: A female-led solar power company in Thailand
Source: IEA (2019c)

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.

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.[64] FPIC is required by various multilateral development banks and other bodies.[65] 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.[66] See Box 7.11.

[64] Free, Prior and Informed Consent (FPIC) is a specific right that pertains to Indigenous peoples and is recognized 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.
[65] 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).
[66] Martire (2020)

Box 7.11: Examples of solar projects serving Indigenous communities
Sources: Natural Resources Canada (2019); Martire (2020)

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 liters of diesel fuel per year, reducing greenhouse gas emissions by 1,743 tons annually. The Indigenous people in this area benefitted from job opportunities during the construction and from cleaner electricity generated.

Figure 7.3: Ft. Chipewyan Solar Farm

Photo: Rob Leavitt, Green Energy Futures (https://www.greenenergyfutures.ca)

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.

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 CSP 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. New cleaning technologies for solar panels, such as the use of electrostatic repulsion, offer the opportunity to substantially reduce water use for this purpose.[67]

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 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 (see Box 7.12). This can be done by project community investment programs as outlined by IFC's community investment handbook.[68]

[67] Engel J. (2022)
[68] IFC (2010)

Box 7.12: Solar company support for community services, India
Source: IFC (2019)

In India, renewable energy company Avaada 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. More information is available at https://avaada.com/sustainability/.

There are many examples of covering infrastructure with solar panels (e.g., parking lots, rail systems, and commercial buildings) to provide shade, help cool urban areas, and provide local power sources. Under a new law in France, car parks with 80 or more spots will need to be equipped with overhead solar power panels.[69] The French national rail service (SNCF) plans to install some 190,000 m^2 of solar panels in 156 stations throughout the country by 2025, and 1.1 million m^2 by 2030, all with the aim to reduce energy consumption by 25%.[70] An intriguing opportunity for solar generation is to place solar panels between railway tracks throughout the rail transport system.

Human rights

Solar PV 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 labor (see Box 7.13)
- Forced resettlement, land take, and violence
- Occupational health and safety, including physical and mental health.

Box 7.13: Use of forced labor in the People's Republic of China
Sources: Murphy and Elimä (2021); Ambrose and Jolly (2021); World Bank (2021)

Recently, there has been a media focus on the Uyghur Region in the People's Republic of China, a major producer of solar panels. In 2021, academic researchers in the United Kingdom (UK) found that the region accounted for approximately 45% of the world's solar-grade polysilicon supply. The study identified 11 companies engaged in forced labor 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 labor camps in Xinjiang province. The newspaper article suggested that up to 40% of the UK's solar farms had panels manufactured by solar panel companies that used interned Muslim Uyghur community members in polysilicon production. Acknowledging this risk, the World Bank has recently issued guidance on measures to avoid forced labor through solar projects.

The Solar Stewardship Initiative has been launched in Europe to address the above concerns (see Box 7.14).

[69] Balkan Green Energy News (2022); Mossalgue (2022)
[70] Euronews Green (2023)

Box 7.14: The Solar Stewardship Initiative
Source: SolarPower Europe (n.d.)

The Solar Stewardship Initiative (SSI) has been launched by SolarPower Europe and Solar Energy UK. It aims to combine supply chain integrity with enhanced Environmental Social and Governance (ESG) performance, providing a robust ESG assurance and certification scheme. SSI-certification relies on third-party, independent supply chain audits, conducted on the basis of international and sector-specific ESG auditing standards. The SSI does not certify sites complicit in forced labor.

The SSI is governed by various types of stakeholders, including industry representatives and civil society actors who are independent of the solar PV industry. It is supported by more than 60 solar companies covering the whole solar value chain and a significant share of the European (including UK) solar market. This multi-stakeholder initiative is working to further develop a responsible, transparent, and sustainable solar value chain—strengthening confidence in how, where, and by whom solar products are manufactured.