



水电水利规划设计总院  
China Renewable Energy Engineering Institute



# LOCAL ENVIRONMENTAL IMPACTS AND BENEFITS OF LARGE-SCALE SOLAR PV PLANTS



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Founded in 1950, the China Renewable Energy Engineering Institute (CREEI) is one of China's leading think tanks in the energy sector. It is among the first specialised research and consulting institutions, formally approved by the National Energy Administration of China. The Institute is dedicated to supporting high-level government decision-making and advancing domestic and global sustainable development with a focus on renewable energy, encompassing planning, policy analysis, engineering consulting, quality supervision, standardisation, and international co-operation. Entrusted by the government, CREEI has taken a leading role in implementing and supporting nearly 20 intergovernmental multilateral and bilateral energy co-operation mechanisms, managing the Office for China-IRENA Cooperation and China-SCO Energy Cooperation Center, among others.

### About IUCN

Created in 1948, the International Union for the Conservation of Nature (IUCN) has evolved into the world's largest and most diverse environmental network. The International Union for the Conservation of Nature (IUCN) is a membership Union uniquely composed of both government and civil society organisations. Its members include expert and influential government, non-government and indigenous peoples' organisations from over 160 countries, and our commissions draw upon more than 16,000 experts worldwide. It provides public, private and non-governmental organisations with the knowledge and tools that enable human progress, economic development and nature conservation to take place together. IUCN is the global authority on the status of the natural world and the measures needed to safeguard it.

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# CONTENTS

<b>ABBREVIATIONS .....</b>	<b>6</b>
<b>EXECUTIVE SUMMARY .....</b>	<b>7</b>
<b>1. SOLAR PHOTOVOLTAIC IN THE ENERGY TRANSITION .....</b>	<b>9</b>
1.1 Development trends and roles .....	9
1.2 Deployment in major markets .....	11
1.3 Environmental aspects and considerations.....	12
<b>2. INTERACTIONS BETWEEN SOLAR PV AND THE LOCAL ENVIRONMENT .....</b>	<b>14</b>
2.1 Overall interactions: Land area needed for solar PV .....	16
2.2 Possible negative impacts on local environmental aspects.....	17
2.3 Potential interactions that can be utilised for co-benefits .....	20
<b>3. EXISTING SOLUTIONS AND PRACTICES FOR SOLAR INDUSTRIES TO PROMOTE SUSTAINABLE DEPLOYMENT .....</b>	<b>26</b>
3.1 Integrated project design and planning .....	26
3.2 Impact mitigation during construction .....	30
3.3 Synergistic operation and maintenance .....	31
3.4 Other solutions and practices.....	36
3.5 From environment to the community .....	38
<b>4. BARRIERS TO ADOPTING ENVIRONMENTALLY FRIENDLY PRACTICES AND HARNESSING CO-BENEFITS .....</b>	<b>39</b>
<b>5. POLICY FRAMEWORK FOR PROMOTING SUSTAINABLE SYNERGIES BETWEEN SOLAR PV PROJECTS AND THE LOCAL ENVIRONMENT.....</b>	<b>43</b>
5.1 Overall policy framework for sustainable solar PV projects.....	43
5.2 Policies and measures to address barriers .....	44
<b>REFERENCES .....</b>	<b>49</b>

# FIGURES

<b>Figure 1</b>	Global cumulative installed solar PV capacity and its share in total renewable capacity and generation, 2015-2024.....	9
<b>Figure 2</b>	Global newly added capacity of solar PV and other renewables, 2015-2024.....	10
<b>Figure 3</b>	Global total installed capacity and electricity generation by solar PV and other renewables, 2023, 2030 and 2050, in 1.5°C Scenario .....	10
<b>Figure 4</b>	Total installed solar PV (right circle) and new additions (left circle) in selected markets and rest of world, 2024 (GW) .....	11
<b>Figure 5</b>	Estimation of total installed solar PV capacity in selected markets, 2024, 2030 and 2050, 1.5°C Scenario .....	12
<b>Figure 6</b>	Different stages of the solar PV life cycle and their interactions with the local environment.....	13
<b>Figure 7</b>	Potential interactions between solar PV plants and the local environment: Impacts and benefits.....	15
<b>Figure 8</b>	Comparison of land areas used for solar PV and golf courses in selected countries .....	17
<b>Figure 9</b>	Potential impacts on the environment during planning and construction processes.....	18
<b>Figure 10</b>	Example of ground temperature difference within and outside of solar PV plants, 2024 .....	21
<b>Figure 11</b>	Example of wind speed difference within and outside of solar PV plants, 2024 .....	22
<b>Figure 12</b>	Possible impacts on vegetation during solar PV plants' construction and operation .....	24
<b>Figure 13</b>	The mitigation hierarchy across the project development cycle of renewables .....	27
<b>Figure 14</b>	Six principles for nature-positive energy siting and permitting .....	28
<b>Figure 15</b>	Measures to avoid and minimise impacts during the construction process.....	30
<b>Figure 16</b>	Potential co-benefits of integrating solar PV and agriculture.....	32
<b>Figure 17</b>	Potential co-benefits of solar grazing .....	33
<b>Figure 18</b>	Terminologies related to solar PV plants' co-benefits with the local environment and biodiversity.....	34
<b>Figure 19</b>	Example of humidity difference within and outside of solar PV plants, 2024.....	35

- Figure 20** Possible interactions and co-benefits of solar PV plants with soil, wind and temperature..... 37
- Figure 21** Key barriers to the adoption of environmentally friendly solar PV operation ..... 39
- Figure 22** Policy framework for maximising synergies between solar PV and the local environment..... 43
- Figure 23** Policies and stakeholders to address major barriers to the adoption of sustainable practices..... 44
- Figure 24** Key steps of a CIA in solar PV project planning..... 46

# BOXES

- Box 1** Environment, nature, biodiversity and ecosystem..... 14

# ABBREVIATIONS

<b>ACE</b>	ASEAN Centre for Energy
<b>°C</b>	degree Celsius
<b>CBD</b>	Convention on Biological Diversity
<b>CIA</b>	cumulative impact assessment
<b>CLEANaction</b>	Coalition Linking Energy and Nature for Action
<b>cm</b>	centimetre
<b>EIA</b>	environmental impact assessment
<b>ESG</b>	environmental, social and governance
<b>EUR</b>	euro
<b>GHG</b>	greenhouse gas
<b>GIS</b>	geographic information systems
<b>GT</b>	gigatonne
<b>GW</b>	gigawatt
<b>IRENA</b>	International Renewable Energy Agency
<b>IUCN</b>	International Union for Conservation of Nature
<b>KBA</b>	key biodiversity area
<b>km<sup>2</sup></b>	square kilometre
<b>kWh</b>	kilowatt hour
<b>LCOE</b>	levelised cost of energy
<b>MW</b>	megawatt
<b>NGO</b>	non-governmental organisation
<b>PV</b>	photovoltaic
<b>RCPEIE</b>	Research Centre for Plateau Energy Industry and Ecology (China)
<b>REN</b>	Renewables for Nature
<b>SEA</b>	strategic environmental assessment
<b>SPIC</b>	State Power Investment Corporation Limited (China)
<b>TNC</b>	The Nature Conservancy
<b>TWh</b>	terawatt hour
<b>UNCCD</b>	United Nations Convention to Combat Desertification
<b>UNFCCC</b>	United Nations Framework Convention on Climate Change
<b>USD</b>	United States dollar
<b>WDPA</b>	World Database of Protected Areas
<b>WETO</b>	World Energy Transitions Outlook

# EXECUTIVE SUMMARY

**Solar photovoltaic (PV) is among the most widely deployed renewable energy technologies worldwide and is set for a rapid expansion over the coming decades.** By the end of 2024, solar PV had contributed 77% of annual capacity additions and 42% of total installed renewable energy capacity. From 2015 to 2024, global total installed solar PV capacity increased by over eightfold. This rapid expansion was driven by declining costs, technological innovations and efficiency improvements, as well as supporting policies and incentives. According to the International Renewable Energy Agency's (IRENA's) 1.5°C Scenario, solar PV is expected to play a vital role in achieving the energy transition aligned with the Paris Agreement's climate target, contributing half of the total needed renewable capacity and 37% of renewable electricity generation by 2050.

**Solar PV deployment can have many impacts, positive and negative, on the environment and biodiversity.** On the positive side, solar PV can reduce greenhouse gas emissions and prevent air pollution by replacing fossil fuel generation, thereby helping tackle the climate crisis and improving public health. With appropriate measures in place, it can also generate co-benefits for environmental and biodiversity enhancement. On the negative side, increased deployment entails growing upstream material demand, indicating larger environmental impacts associated with the mining and processing of minerals used for solar PV manufacturing. Further, solar PV plants can have many interactions with the local environment and impact biodiversity. As solar PV expansion accelerates, policy makers and stakeholders need to understand these interactions and urgently implement appropriate measures and policies.

**Land-use implications for solar PV deployment remain one of the most complex topics, with concerns raised about possible competition with agricultural and other land uses.** Appraisals of the deployment of solar PV projects in major markets have suggested that if governments adopt proper assessment and planning processes, current and future solar PV plants are not likely to compete with agriculture at a global level and in major markets. However, for countries that already face land scarcity issues and have high-density populations, land-use competition may be further intensified. To avoid such issues, implementing an integrated planning process involving stakeholders across multiple sectors is necessary.

**Any negative impacts of a solar PV plant on the local environment depend heavily on the selected location, construction timing and approaches, and ecological conditions prior to deployment.** Negative impacts may arise if the projects are deployed in areas that have high biodiversity value, provide vital ecological services or serve as key habitat for wildlife. The construction of solar PV projects and the deployment of powerlines remove vegetation from land, seriously affecting wildlife habitat and the original ecosystem. These actions can also cause pollution, degrade land and increase flooding risks. Another risk involves invasive species, which may be introduced if replantation is not based on native species. Meanwhile, during the operation phase, collisions and electrocutions between wildlife and PV panels and powerlines can injure and kill wildlife, and the fencing of solar PV plants causes habitat fragmentation. Further, large-scale projects can change the landscape structurally and visually, thereby impacting local aesthetics and cultural heritage. Finally, solar PV plants can affect the microclimate and environmental factors in the areas where they are located, such as temperature, humidity, soil conditions, vegetation growth and biodiversity.

**Addressing these potential impacts requires incorporating environmental and biodiversity considerations into the early stages of project design and planning.** Project developers and industry stakeholders can adopt many existing measures and tools. This includes a mitigation hierarchy that includes avoidance, minimisation and restoration – and offsets as the last option after all other measures have been exhausted. Developers can adopt six key principles for site selection that are positive for nature, including accelerating nature-positive development; co-utilising; conserving, restoring and enhancing; monitoring and adapting; extending the useful life; and engaging local actors. Many existing databases and mapping tools for assessing biodiversity

sensitivity and potential risks can help solar developers identify low-risk locations and minimise negative impacts on the environment. During construction, careful assessment of timing and practices can avoid major threats to habitat and disturbance to wildlife, complemented by revegetation measures and planned wildlife corridors and passages.

**Under specific conditions, some environmental impacts can turn into co-benefits between energy generation and environmental and biodiversity enhancement.** Combining agricultural activities with solar PV plants, with necessary modifications, can improve land-use efficiency, enhance food security and generate additional income. For instance, livestock grazing in solar PV plants can reduce fire hazards from overgrown vegetation, save costs on vegetation management, and possibly increase meat and milk production. Under certain conditions, solar PV plant operations can coexist with improved vegetation coverage and enhanced biodiversity. In arid and semi-arid conditions, solar PV deployment can help restore degraded land, such as abandoned mining sites and brownfields, and help control desertification and sandstorms. When solar PV is deployed on water bodies, it may improve water quality and help control algal blooms. In areas where agriculture lacks access to power, solar PV can be combined with agriculture to power irrigation systems and improve livelihoods.

**To date, only a few countries and markets have systematically integrated considerations of solar PV plants' impacts on local environments into industrial practice.** In countries and regions with larger-scale installed solar PV capacity, such as China, Europe, Japan and the Republic of Korea, as well as the United States, solar PV developers often use environmental impact assessments to avoid and minimise negative impacts during site selection. Furthermore, an increasing number of solar PV projects have begun to explore and harness the co-benefits of combining solar PV plants with agricultural activities, livestock grazing, biodiversity enhancement, degraded land recovery, desertification and sandstorm control, aquacultural activities, and other purposes. Such practices have also been incorporated into pilot projects deployed in East African countries. A number of international platforms and initiatives, based on engagement with energy and conservation stakeholders, have started joint efforts to raise policy makers' awareness of this matter and provide guidelines, tools and best practices for industrial stakeholders.

**Many barriers impede the expansion of sustainable practices that aim to avoid negative environmental impacts at the design and planning stage, or to harness co-benefits between solar generation and environmental improvement.** These barriers include additional costs for adaptive equipment and maintenance, a lack of knowledge or experience, unclear or inconsistent land-use policies, and a lack of industrial standards. These barriers can discourage industrial players from adopting existing solutions and sustainable practices. They can further cause economic loss to project developers due to project delay and cancellation, which are linked to local communities' concerns about and opposition to negative environmental impacts.

**Policies and measures are needed to address these barriers and further promote sustainable practices.** An overall policy framework should be based on considerations of balancing energy, biodiversity and land use at the regional, national and subnational levels. Policy makers can adopt many existing tools and measures – including strategic environmental assessments and cumulative impact assessments, long-term targets that integrate energy and environmental considerations, and consistent land-use policies – to protect areas with high biodiversity risks. Financial and fiscal incentives can be used to encourage sustainable practices that can avoid most negative impacts during the site selection process and to support pilot projects that can harness co-benefits. Industrial standards and guidelines are urgently needed to fill the knowledge gap. This gap can be further closed through training and capacity-building for solar PV industrial players and stakeholders. Financial sectors, including multilateral development banks and international financial institutions, can play a crucial role by enabling environmental requirements for the development of projects.

# CHAPTER 1

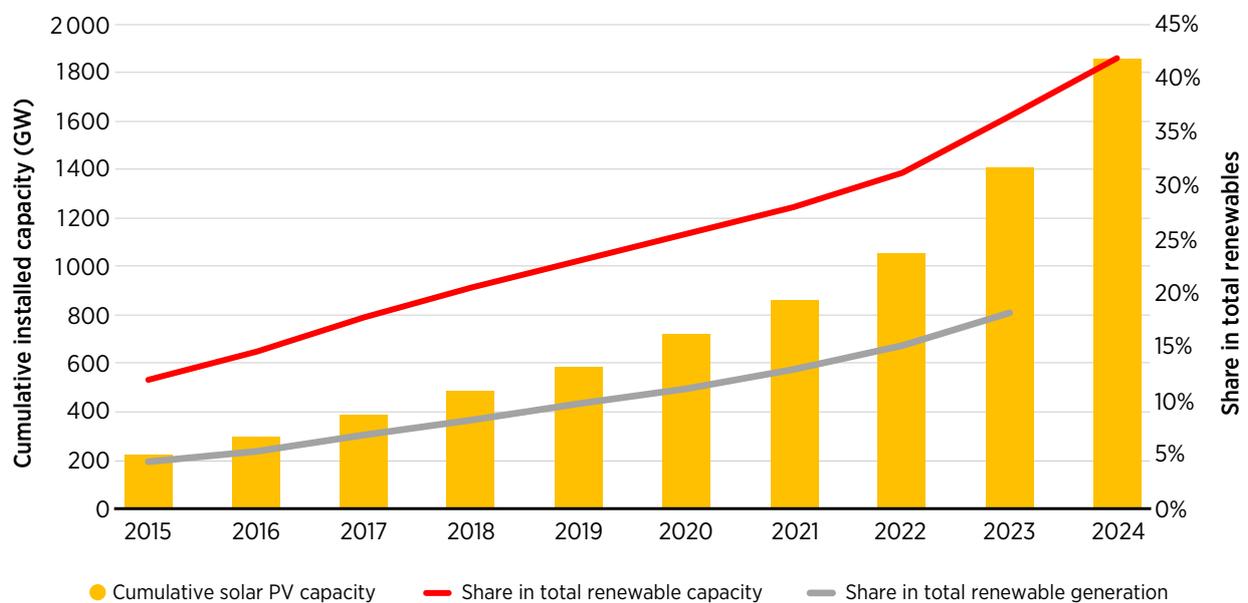
# SOLAR PHOTOVOLTAIC

# IN THE ENERGY TRANSITION

## 1.1 DEVELOPMENT TRENDS AND ROLES

Solar PV has become one of the most widely deployed renewable energy technologies globally. Starting in 2023, solar PV surpassed hydropower and became the largest installed renewable power capacity. By the end of 2024, global total installed solar PV capacity (1859 gigawatts [GW]) accounted for 42% of total installed renewable energy capacity (4 443 GW) (see Figure 1). It accounted for over 77% of total renewable additions (582 GW) in 2024 and contributed around 18% of total renewable electricity generation (8 928 terawatt hours [TWh]) in 2023. Globally, solar PV electricity remains the third-largest renewable electricity source, after hydropower and wind (IRENA, 2025a).

**Figure 1** Global cumulative installed solar PV capacity and its share in total renewable capacity and generation, 2015-2024

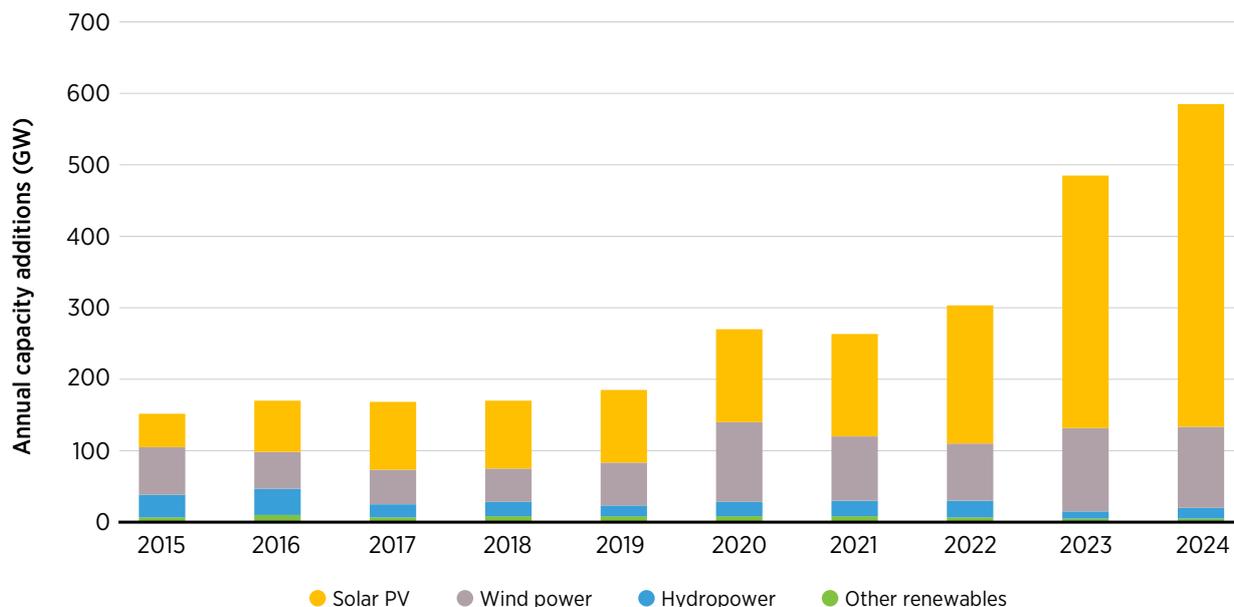


Source: (IRENA, 2025a).

Notes: GW = gigawatts; PV = photovoltaic.

In the last decade, from 2015 to 2024, solar PV projects have expanded rapidly, with global installed solar PV capacity increasing by over eightfold. In 2024, global solar PV additions were twice the historical cumulative deployment in 2015 (see Figures 1 and 2). This rapid expansion was driven by many factors, including declining costs of solar PV technologies, technological innovations and efficiency improvements, as well as rigorous supporting policies and incentives in major markets. Among all these factors, the lower cost of solar PV electricity is one of the most attractive to industries and countries. From 2010 to 2024, the global weighted-average levelised cost of energy (LCOE) of utility-scale solar PV plants declined by 90%, from USD 0.417 (United States dollar) per kilowatt hour (kWh) to USD 0.043 per kWh. In 2024, the global average cost of solar PV electricity was 41% lower than the least-cost fossil fuel electricity, making it the preferred energy source (IRENA, 2025b).

**Figure 2** Global newly added capacity of solar PV and other renewables, 2015-2024

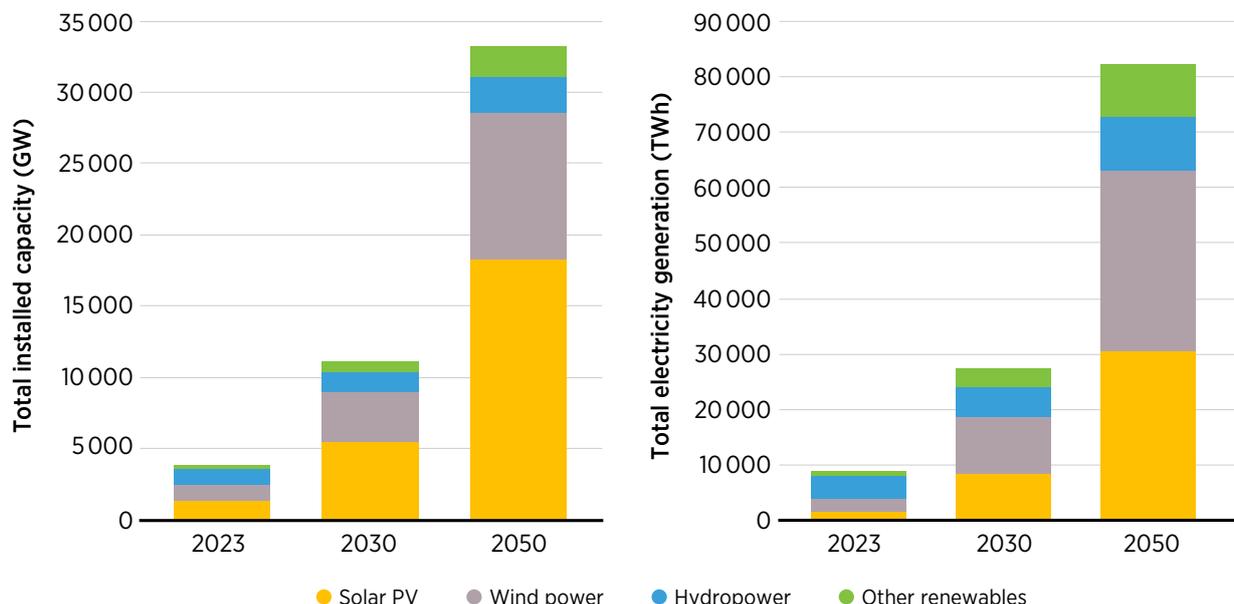


Source: (IRENA, 2025a).

Notes: GW = gigawatts; PV = photovoltaic.

According to the International Renewable Energy Agency’s (IRENA’s) *World energy transitions outlook 2024* (WETO), to keep the world aligned with the Paris Agreement’s climate target, renewable energy will need to provide 68% of electricity by 2030 and 91% by 2050 (IRENA, 2024a). Solar PV is expected to play a vital role in achieving the transition targets. It will need to increase from its current level to over 5 457 GW by 2030, necessitating approximately 600 GW of annual additions from 2025 to 2030. Looking towards 2050, total installed capacity will need to reach over 18 200 GW to remain aligned with the Paris climate target, contributing over half of the total needed renewable capacity under the 1.5°C Scenario (see Figure 3). The share of solar PV in total renewable electricity generation will also need to increase from 18% in 2023 to 31% by 2030 and 37% by 2050. To meet these deployment targets, over USD 330 billion in investments will be needed each year for solar PV projects, a 2.6-times increase from current levels (IRENA, 2024a).

**Figure 3** Global total installed capacity (left) and electricity generation (right) by solar PV and other renewables, 2023, 2030 and 2050, in 1.5°C Scenario



Source: (IRENA, 2025a).

Notes: GW = gigawatts; PV = photovoltaic.

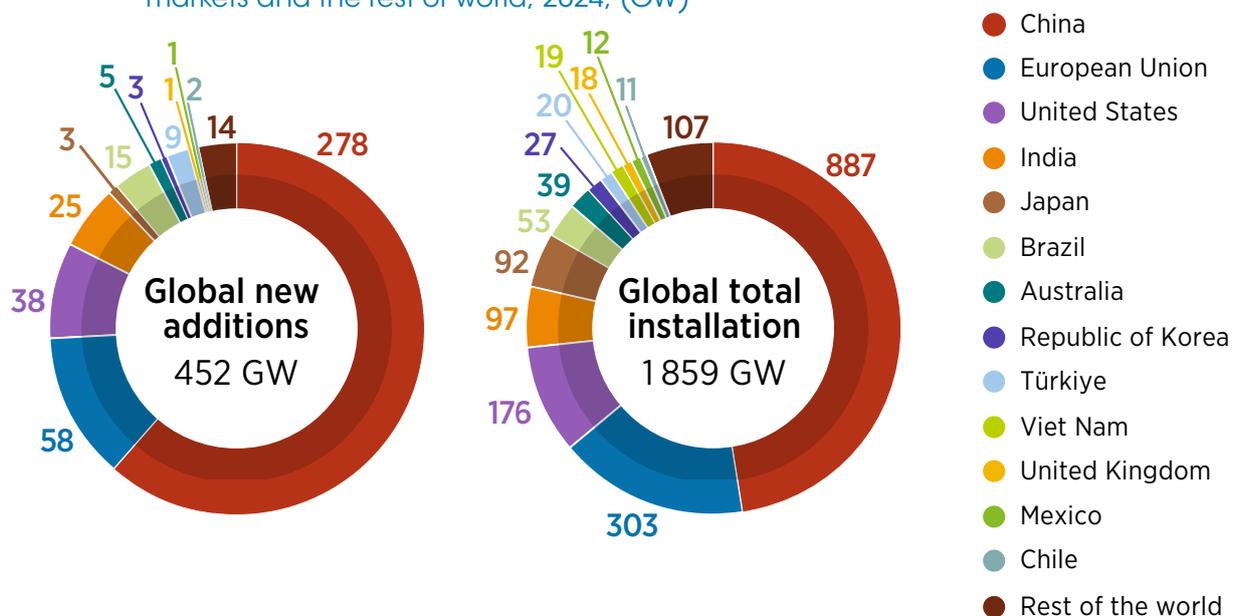
## 1.2 DEPLOYMENT IN MAJOR MARKETS

While solar PV has experienced rapid global expansion, its deployment varies across regions and countries. G20 members, including Australia, Brazil, China, the European Union, India, Japan and the United States, are among the markets with larger capacity deployment.

China has significantly scaled up solar PV deployment over the last two decades. By 2024, China accounted for 62% of global newly added solar PV capacity and 48% of total installed solar PV capacity. However, back in 2010, China's total installed solar PV capacity was 0.8 GW out of the 39 GW global total, which was much smaller than the deployments in many developed markets, including Belgium, the Czech Republic, France, Germany, Italy, Japan, Spain and the United States. By implementing a robust policy framework, including long-term energy strategy (e.g. Five-Year Plans), financial and fiscal incentives, industrial guidelines and innovations, and targeted investment, solar PV panels installed in China increased to a level (887 GW) that was almost double the combined total of the aforementioned countries by 2024 (IRENA, 2025a).

Apart from China, the European Union (303 GW), United States (176 GW), India (97 GW), Japan (92 GW), Brazil (53 GW), Australia (39 GW), Republic of Korea (27 GW), Türkiye (20 GW) and Viet Nam (19 GW) were some of other markets with the largest installed capacity of solar PV power as of 2024 (IRENA, 2025a) (see Figure 4). Recently, however, some countries from different regions have begun to show strong momentum in solar PV deployment. For example, in 2024, Egypt and South Africa deployed 0.7 GW and 0.5 GW solar PV plants, bringing the total installed capacity to 2.6 GW and 6.2 GW, respectively. Saudi Arabia has deployed 1.8 GW of solar projects, bringing its total capacity to 4.3 GW. The United Arab Emirates reached 5.4 GW of total installed solar PV capacity, following 2 GW of added capacity in 2023 and another 70 megawatts (MW) in 2024 (IRENA, 2025a). However, the majority of developing markets are experiencing slower expansion, calling for more investment and robust supporting policies.

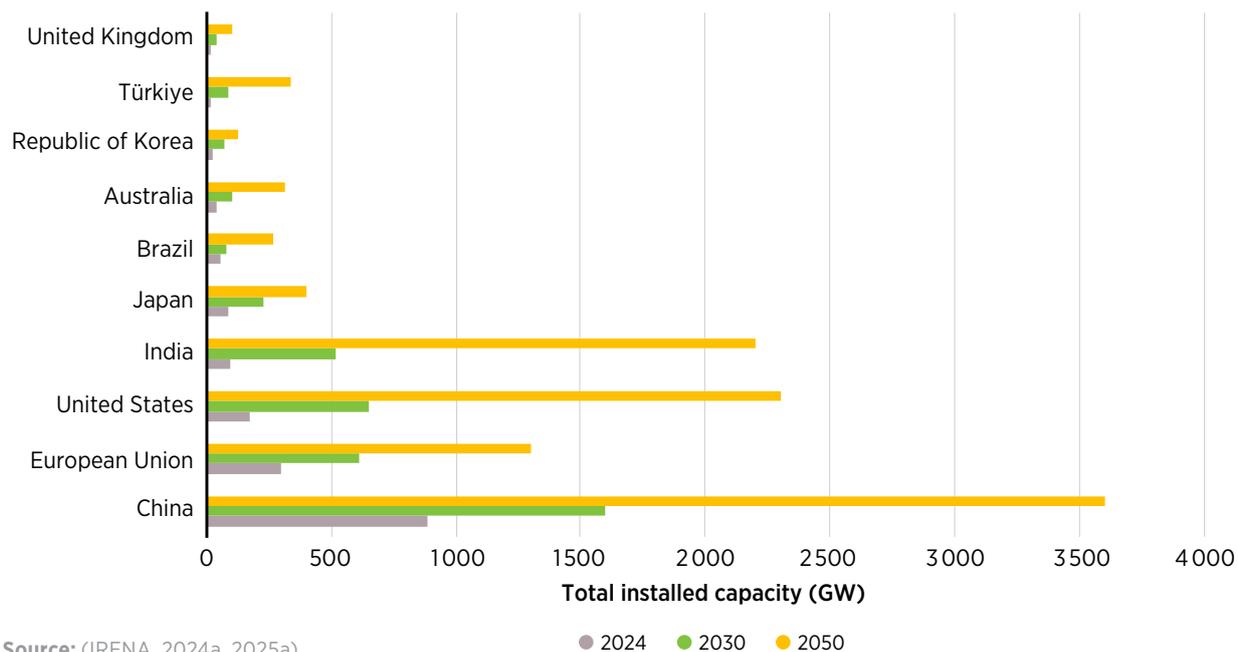
**Figure 4** Total installed solar PV (right circle) and new additions (left circle) in selected markets and the rest of world, 2024, (GW)



Source: (IRENA, 2025a).

Based on IRENA's 1.5 degree Celsius (°C) Scenario, it is estimated that G20 member countries will need to contribute the majority (over 72%) of global solar PV additions by 2050, driven by economic activities and energy demand in these markets. It is estimated that Australia, Brazil, China, the European Union, India, Japan and the United States will remain some of the markets with the largest solar PV deployment in the next couple of decades. This estimation is based on the assumption that ambitious targets, supportive policy frameworks, and dedicated financial and fiscal incentives can be adopted (see Figure 5).

**Figure 5** Estimation of total installed solar PV capacity in selected markets, 2024, 2030 and 2050, 1.5°C Scenario



Source: (IRENA, 2024a, 2025a).

Note: GW = gigawatts.

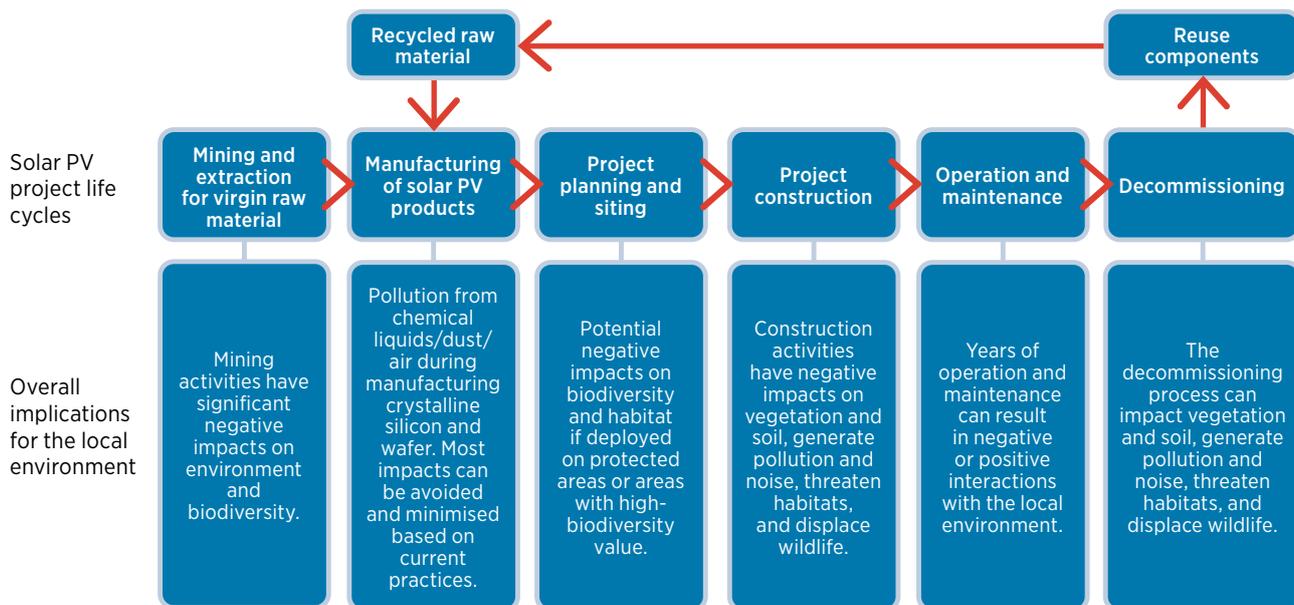
### 1.3 ENVIRONMENTAL ASPECTS AND CONSIDERATIONS

Among the positive environmental aspects of solar PV, its potential to contribute to greenhouse gas (GHG) reductions and address climate change challenges is clear and promising. It is estimated that deployed solar PV projects between 2019 and 2023 worldwide avoided 1.1 gigatonnes (Gt) of GHG emissions annually (which would have been generated by fossil-fuel-based power plants to provide the same power supply). This accounted for around 3% of global total GHG emissions in 2024 (IEA, 2025). IRENA's 1.5°C Scenario suggests that replacing fossil fuel power plants with solar PV power plants could avoid 3.2 Gt of carbon dioxide annually by 2050 (IRENA, 2024a).

Solar PV can also reduce air pollution, which is often linked to fossil fuel power generation. For example, coal power plants are major sources of air pollutants, including sulphur oxide, nitric oxide and nitrogen dioxide, black carbon, and PM2.5. These air pollutants represent major threats to public health and are linked to around half of premature deaths worldwide (WHO, 2023). In the United States, a study estimated that about one coal power plant caused 1000 excess deaths over two decades from 2000 to 2020 (NIH, 2023). Replacing fossil fuel generation with solar PV electricity and other renewables, combined with the electrification of road transport and the heating sector, can significantly reduce air pollution and thereby improve public welfare.

Solar PV has a range of other environmental impacts that can either be positive or negative. These can occur across the whole value chain, including upstream materials demand (see Figure 6). As demand for solar PV technologies increases significantly, so do the potential negative environmental impacts associated with the mining and processing of virgin minerals used in solar panel manufacturing. When areas with active mining and processing industries overlap with areas of high biodiversity value and proper mitigation measures are not in place, the impacts on ecosystems can be significant. These impacts include habitat disruption; soil erosion; water, air and soil pollution; and increased risks of geohazards. IRENA estimates that, in a scenario aligned with the Paris climate goals, the material needs for manufacturing solar PVs, including aluminium, copper and silver, would reach 2.6 million tonnes (t), 0.18 million t and 4 000 t, respectively, by 2030 (IRENA, forthcoming). If all these material demands come from mining virgin minerals, they will cause severe impacts on land, water and marine ecosystems. Dedicated policies and measures are therefore urgently needed to promote the circular economy across the entire supply chain and reduce the demand for virgin minerals.

**Figure 6** Different stages of the solar PV life cycle and their interactions with the local environment



When solar PV plants reach the end of their service life (around 30 years or longer), their handling and disposal can have environmental impacts. If the damaged or decommissioned solar PV panels are not properly stored or treated, heavy metals or hazardous substances in the panels can pollute land, water, air and the local ecosystem, threatening public health. For example, the majority of currently installed solar panel backsheets are fluorine-based for better durability performance. Without proper measures, burning these solar panel backsheets can produce highly toxic hydrogen fluoride, which can be fatal to animals, including humans. Solar panels and attached batteries contain heavy metals (e.g. lead, copper, zinc and nickel). When decommissioned solar panels are not stored or managed properly, leakage of these heavy metals can pollute soil and groundwater, which could negatively affect local ecosystems.

Addressing these negative environmental impacts requires first and foremost adopting circular economy principles (e.g. reducing, reusing and recycling) throughout the lifecycle of solar PV projects, including design, manufacturing, decommissioning, transportation, storage and end-of-life treatment. Promoting circularity-based solar PV design can minimise the use of chemicals and hazardous materials. Environmental regulations and mandates offer policy tools to prevent landfilling and encourage the reusing and recycling of solar panels, minimising environmental footprints and pollution.

In the state of Victoria (Australia), for example, the government has announced regulations to ban solar panels from landfills, thereby avoiding relevant environmental impacts. Dedicated policies and incentives have been adopted at the national, regional and subnational levels in China, the European Union, Japan and the United States to promote the circular economy for the solar PV industry and ensure sustainable practices for decommissioned solar PV plants, minimising potential negative environmental impacts. A further benefit of promoting the circular economy for the solar industry is job creation for professional companies and trained workers to transport, handle and treat end-of-life solar PV panels.

The solar PV industry must urgently address solar PV's environmental impacts across its life cycle. Leading solar PV companies have commonly employed expertise and resources to assess the environmental, social and governance (ESG) performance of their supply chains and operational projects. While the ESG approach offers an important means for companies to demonstrate compliance, it may not capture all relevant environmental impacts and interactions with biodiversity and local communities across diversified markets (IRENA, 2024b). Environmental impacts can vary from place to place, and it is important to understand the potential interactions between solar PV power plants and local environmental factors.

## CHAPTER 2

# INTERACTIONS BETWEEN SOLAR PV AND THE LOCAL ENVIRONMENT

Solar PV power plants<sup>1</sup> can interact with local environments in various ways, with both positive and negative impacts on nature and land uses, such as agriculture. Nature impacts and their influence on biodiversity are highly specific to the locations, timing (e.g. the season when projects are installed), and the approach and deployment methods used during plant construction. Whether the impacts are negative or positive depends on environmental and ecological conditions prior to the solar PV installation (see Box 1).

### Box 1 Environment, nature, biodiversity and ecosystem

“Nature”, “biodiversity”, “ecosystem” and “environment” are some of the terms used in conservation-related contexts. These terms overlap in many cases but have different contexts and implications.

“Nature” usually refers to the physical world, such as plants, animals, rocks, rivers and landscapes. It includes both living and non-living components of the natural world (IUCN, 2025). Traditionally, nature does not indicate human activities or things created by humans, such as buildings, plastics or cars. As part of nature, “biodiversity” focuses more on living components and the variability among living organisms from all sources. It highlights the importance of diversity within species, between species and within ecosystems (CBD, 2024). Within a specific space, an “ecosystem” is a dynamic complex of plant, animal and micro-organism communities, and their non-living environment, interacting as a functional unit (UNEP, 2021). Damaging a balanced ecosystem can change the ecological services it provides to nature. In broader terms, “environment” can have many definitions. It usually refers to the physical factors surrounding the living organism, including both natural and human-made components such as water, air, land and the conditions that support life.

These terms often overlap and can be interchangeable in many cases. Nature is the broadest concept, including both living and non-living components. Biodiversity is one of the key indicators for a healthy ecosystem. In the context of discussions on the environmental impacts of energy facilities, energy projects influence local environmental aspects, such as the atmosphere, water, soil and surrounding ecosystems. These changes can threaten local biodiversity and wildlife habitat in the surrounding area. Over time, these environmental impacts may break the balance of the previous ecosystem. This means weakened or lost previous ecological services, or the emergence of new ecological services it can provide.

**Based on:** (CBD, 2024; IUCN, 2025; UNEP, 2021).

Negative impacts may arise during site selection, construction and the operation of solar PV plants. These negative impacts include disturbing vegetation and wildlife during construction, habitat loss, soil degradation, water pollution and wildlife displacement, among others. For example, the construction of solar plants and

<sup>1</sup> Solar PV plants in this report are focused on utility-scale solar plants from several MW to GW of capacity, excluding smaller-scale solar PV projects, such as residential solar rooftops. Utility-scale solar PV projects accounted for around 60% of global total installed solar PV capacity in 2024. They usually cover a larger land area, indicating larger interactions with the local environment. The environmental impacts of smaller-scale solar PV projects and solar PV supply chains, including upstream mining and manufacturing, will be analysed separately in future analysis.

deployment of powerlines removes vegetation from land, affecting wildlife habitat and increasing flooding risks during heavy rain. Replantation under PV panels, if not based on native species, may introduce invasive species and destroy the original ecosystem. The negative impacts and risks could be more significant when solar PV plants are sited in areas with high ecological values or fragile ecosystems.

Positive impacts may arise from careful site selection, proper design and environmentally friendly maintenance of solar PV projects. When solar PV plants are deployed on disturbed or degraded land, they may have positive impacts by accelerating the process and improving the effectiveness of land recovery and ecosystem restoration. For example, over years of operation, shading from solar PV can affect the solar radiation reaching the ground and therefore cause changes in temperature, evaporation, humidity, plant growth and other issues. Changes in these environmental factors do not provide benefits per se. However, given solar PV plants' effects on local environmental factors, the rebalanced ecosystem and the services it can provide might be useful in certain climatic conditions. For example, reduced water evaporation can benefit agricultural activities in dry areas, and reduced wind speed may be beneficial in areas where controlling dust and sandstorms is an issue. By implementing proper measures and sustainable practices, these environmental changes and the rebalanced ecosystem can be linked to multiple benefits, including improved local biodiversity and the creation of additional ecological values (see Figure 7). These ecological values can be further harnessed through agricultural or economic activities, such as crop and fruit production, pollinator conservation, livestock (e.g. sheep, goats, cows) grazing and aquaculture (see Chapter 3).

**Figure 7** Potential interactions between solar PV plants and the local environment: Impacts and benefits

	DIRECT INTERACTIONS	IMPACTS ON MICRO-CLIMATE CONDITIONS, SOIL AND VEGETATION	IMPACTS ON WILDLIFE, HABITAT AND ECOLOGICAL SERVICE/ FUNCTION	IMPACT ON PEOPLE AND LOCAL COMMUNITY
Overall impacts on materials and land use	<ul style="list-style-type: none"> <li>Material demand</li> <li>Land use</li> </ul>	<ul style="list-style-type: none"> <li>Vegetation loss (e.g deforestation) driven by increased mining activities</li> </ul>	<ul style="list-style-type: none"> <li>Threats to wildlife and their habitat</li> </ul>	<ul style="list-style-type: none"> <li>Land use competition</li> <li>Threats to public health linked to extractive industry waste</li> </ul>
Project design and planning phase	<ul style="list-style-type: none"> <li>Overlapping with protected area, key biodiversity area or cultural heritages</li> </ul>		<ul style="list-style-type: none"> <li>Threats to wildlife and their habitat</li> <li>Wildlife habitat loss or fragmentation</li> </ul>	<ul style="list-style-type: none"> <li>Local jobs</li> </ul>
Construction phase	<ul style="list-style-type: none"> <li>Land clearing</li> <li>Excavation for foundation and cables</li> <li>Noise and waste</li> </ul>	<ul style="list-style-type: none"> <li>Vegetation loss</li> <li>Introduction of invasive species</li> <li>Pollution</li> <li>Soil erosion/ degradation</li> </ul>	<ul style="list-style-type: none"> <li>Wildlife habitat loss</li> <li>Disturbance to nesting and breeding</li> <li>Risk of flooding</li> </ul>	<ul style="list-style-type: none"> <li>Increased risks to local communities due to pollution and geological hazard</li> </ul>
Operation and maintenance	<ul style="list-style-type: none"> <li>Panel shading</li> </ul>	<ul style="list-style-type: none"> <li>Temperature</li> <li>Evaporation</li> <li>Wind speed</li> <li>Soil quality</li> <li>Vegetation coverage</li> <li>Vegetation diversity</li> <li>Water demand for cleaning</li> </ul>	<ul style="list-style-type: none"> <li>Enhanced or restored ecological services</li> <li>Recovery of degraded land</li> <li>Increased biodiversity richness</li> </ul>	<ul style="list-style-type: none"> <li>Visual impacts to local community</li> <li>Additional income</li> <li>Local jobs</li> </ul>

This chapter explores the possible interactions between large-scale solar PV projects and the local environment at different stages, including planning and siting, construction, and operation and maintenance. These interactions concern land-use competition, negative impacts on the local environment and the potential for environmental impacts to be harnessed for co-benefits.

## 2.1 OVERALL INTERACTIONS: LAND AREA NEEDED FOR SOLAR PV

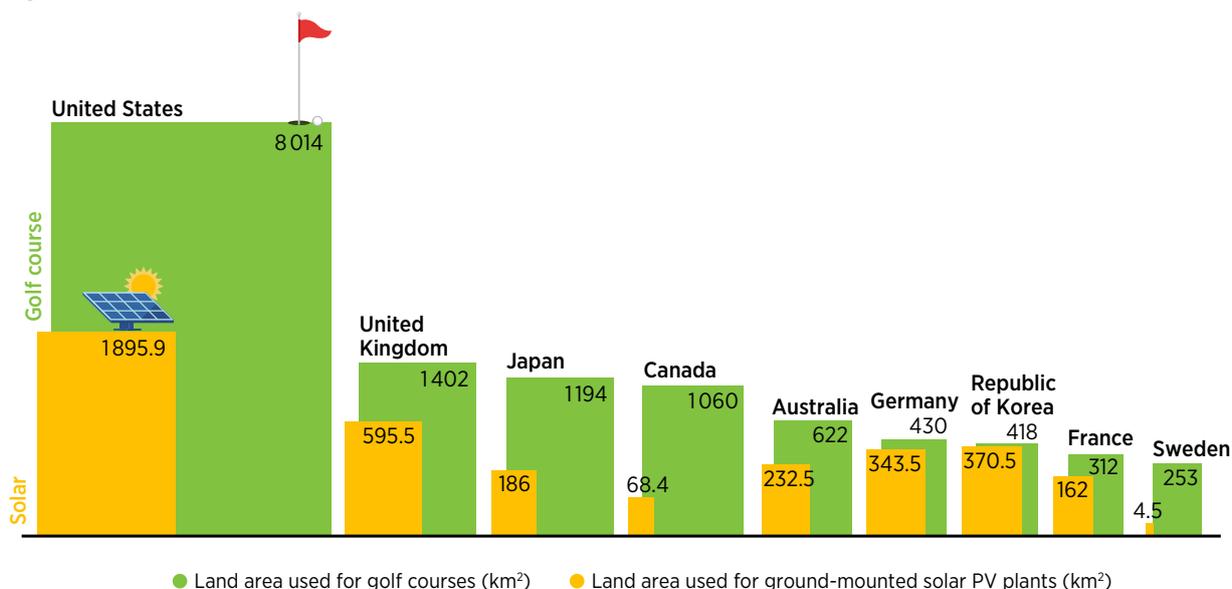
Among all the potential interactions between solar PV and the environment, the land-use implications of solar PV deployment remain one of the most complex topics. While rapid deployment of solar PV projects is needed for the energy transition, concerns have been raised about possible competition with agriculture and other land uses.

The land area required for each MW of utility-scale solar PV plants varies depending on location, solar radiation, technology used and electricity generation efficiency. In China, it is estimated that every MW of utility-scale ground-mounted solar PV plants requires 1-2 ha of land, based on existing technologies (SPIC, 2025). In the scenario aligned with the Paris climate target, it is estimated that solar PV deployment in China would likely cover less than 1% of the country's land area by 2050. Considering that most newly added solar power plants are being deployed on degraded land and to support the control of desertification (which covers over 13% of China's land area), solar PV deployment is unlikely to compete with agricultural land or land with high biodiversity values.

In the United Kingdom, each MW of solar PV project needs around 2 ha of land area, based on the estimation of current deployment (Blaydes *et al.*, 2025). To meet the most ambitious solar PV deployment targets for 2050, large-scale solar farms would account for less than 0.7% of the United Kingdom's land area. In that case, even though all new solar farms would be deployed on agricultural land in the United Kingdom, it would take less than 2% of all farmland, indicating unlikely competition with food production (Blaydes *et al.*, 2025). In the United States, every MW of solar farms requires 3-4 ha of land area (SETO, 2021; Wyatt and Kristian, 2021). Based on an ambitious assumption, and without considering short-term political changes, solar PV deployment aligned with the Paris climate target would require less than 0.5% of the United States' land area, or 1% if combined with agricultural land.

Based on these estimates across major markets, the solar PV installations needed for 2050 are unlikely to take up a large share of land. If relevant policy making and planning processes can be integrated, solar PV deployment does not need to compete significantly with agriculture or biodiversity conservation. It is estimated that the total land area used for solar PV globally in 2023 was around 3-7 million ha, which is less than 0.1% of the global agricultural land area. In 2050, such a share could increase to between 0.2% and 1.5% (FAO, 2023; IRENA, 2025a). This indicates an unlikely possibility of land-use competition at the global scale. When considering possible co-benefits of combining solar PV and agricultural activities, land-use competition becomes less likely because both energy and agricultural production can be synergised (see Chapter 3). On the other hand, if a proper assessment and planning process can be adopted, new solar PV deployment can be prioritised for degraded or disturbed land, thereby minimising negative impacts (see Chapter 3). Furthermore, land areas used for other purposes that either damage biodiversity or compete with agriculture have been much larger than those used by solar PV. For example, in Australia, Canada, Japan, the United Kingdom, the United States and many other countries, land areas used for golf courses can be several or over ten times larger than the areas used for utility-scale solar PV (Weinand *et al.*, 2025) (see Figure 8).

**Figure 8** Comparison of land areas used for solar PV and golf courses in selected countries



**Source:** (Gabbatiss and Lempriere, 2025).

**Notes:** The figure shows a comparison of the existing status based on accessible data; it does not indicate any future situation. km² = square kilometre..

It is worth noting that the estimated land-use competition between solar PV and agriculture globally and in the markets mentioned above may not prevail in countries where land-use competition for economic activities is already intense. For example, small island developing states may already face issues of land scarcity and high-density populations. In this case, careful assessment and integrated planning are necessary to avoid land-use competition. For other markets, assessments should be based on their specific regional context, solar radiation levels, territory context, population density and the scale of degraded lands. Examples of this include marginal lands or lands designated as low-impact or having a low biodiversity value but that may still be occupied by local communities for their livelihoods. The utilisation of these lands must consider and protect the interests of these local communities. Innovative solutions, such as combining solar PV with the building structure or agricultural activities (see Chapter 3), can increase renewables deployment and reduce land scarcity.

## 2.2 POSSIBLE NEGATIVE IMPACTS ON LOCAL ENVIRONMENTAL ASPECTS

### Possible impacts on vegetation and soil by land clearing

The construction of solar PV power plants often involves land clearing, posing significant threats to vegetation and soil quality. For example, project preparation for a 10 MW solar plant may require clearing over a dozen hectares of land and native vegetation. Vegetation loss during land clearing will take time to recover, even with vigorous replantation measures. In China, an assessment of six large-scale solar power plants in Gansu Province found that native vegetation coverage decreased from the original 10-15% to below 2% after land clearing. Without proper replantation measures, it can take at least three years for vegetation to naturally recover to half the level before land clearing (Zhou and Wang, 2019).

Removing vegetation can cause soil erosion and degradation. Similar impacts also occur during the construction process, including deep excavation for installing cables and foundations. During land clearing and construction, surface soil structures will be damaged, along with soil compaction and decreased fertility (Liu *et al.*, 2025). Vegetation loss across such a large area will increase the risk of soil erosion and land degradation. This is particularly the case for solar PV plants deployed on sloping surfaces (e.g. mountains), where the tilted panel surface may alter the ground surface rainfall and increase soil erosion. Further, loss of ground vegetation and soil erosion will increase the risks of surface runoff and flooding during rainy seasons.

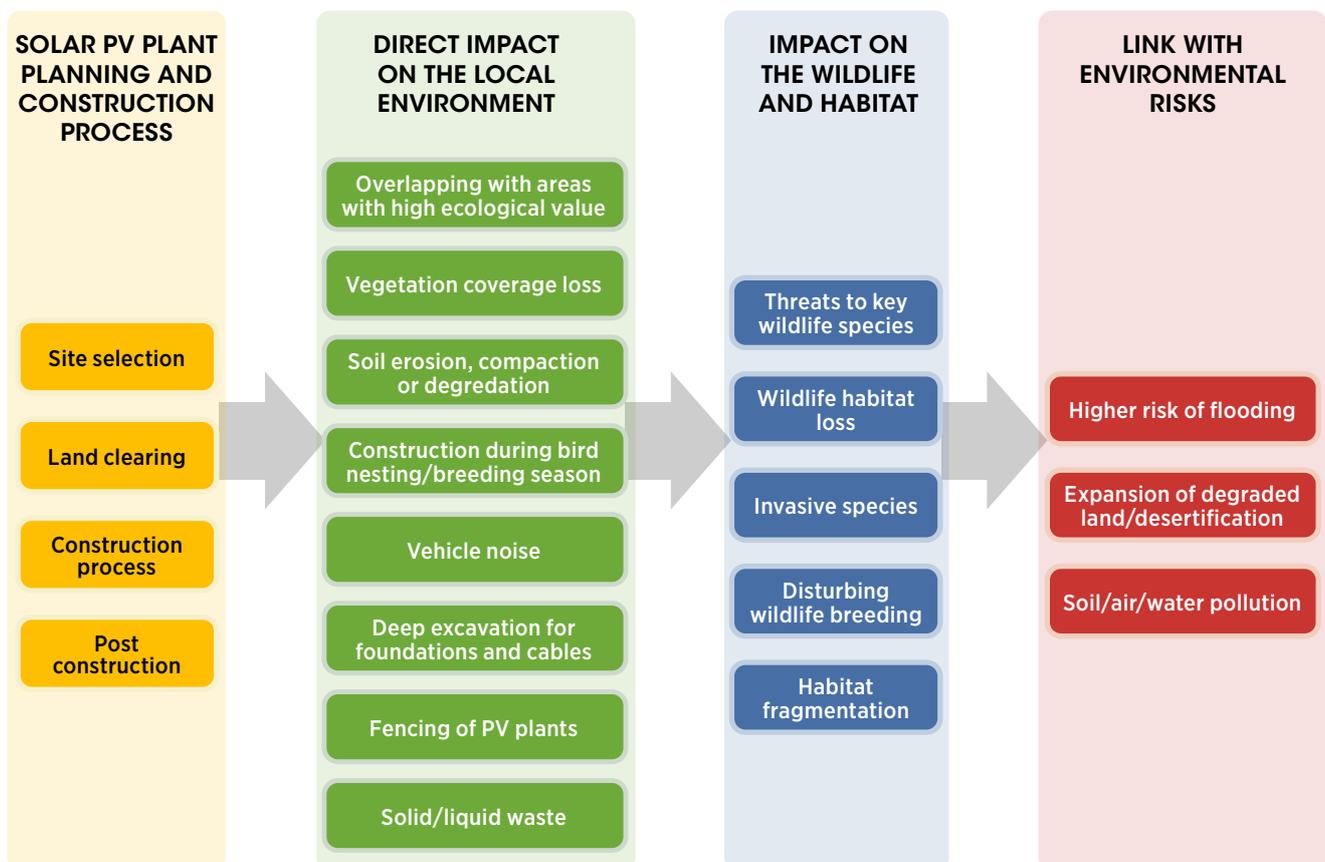
When solar panels are deployed in areas affected by the desertification process, construction may also damage existing biological soil crusts on sands, which protect arid lands from desertification. Therefore, the construction process can also increase the risk of desertification and sandstorms.

### Disruption of habitat and biodiversity

Solar PV construction causes vegetation loss, whether it is trees, shrubs, pasture or other vegetation. When solar PV projects are deployed on land covered by trees and shrubs, the construction process and clearing of woods may cause or accelerate the deforestation process. Forests are home to over 80% of terrestrial biodiversity, including 80% of amphibians, 75% of birds and 68% of mammals (FAO and UNEP, 2020). Due to its high value to the global ecological system, around 21% of the world's forested area has been defined as protected forests by national or regional laws (Davis, 2025). Forested areas provide many fundamental ecosystem services to the whole planet, such as climate regulation, air and water purification, and flood control, among others. Similarly, pastureland has significant ecological value and plays a key role in biodiversity and the livestock industry.

Land clearing, deep excavation for panel foundations and cables, and construction of roads and maintenance buildings attached to power plants cause habitat loss for wildlife (see Figure 9). These activities can cause a significant reduction in the ecological services of the disturbed area due to the disruption of the previous balance within the specific ecosystem (Zhou *et al.*, 2019). Further, fencing of large-scale solar PV plants can affect wildlife movements, which are crucial for accessing food, water and shelter, as well as for reproductive activities. Vehicle noise during the construction process may also affect the breeding season of wild animals.

**Figure 9** Potential impacts on the environment during planning and construction processes



If located in areas with high biodiversity values or in key wildlife habitats, the operation of a solar PV plant can significantly impact biodiversity and wildlife habitats. A study estimates that, as of 2020, over 200 solar PV projects had been deployed within key biodiversity areas (KBAs) (Rehbein *et al.*, 2020). KBAs are defined by the International Union for Conservation of Nature (IUCN), BirdLife International and other conservation organisations as areas that can contribute significantly to global biodiversity and overall health. Due to these potential negative impacts, international conservation organisations have proposed that new solar PV plants should avoid protected areas and be prioritised for disturbed areas (see Chapter 3). It is worth noting that land areas defined as having low biodiversity values can still have important ecological functions. Deploying solar PV projects in these areas still requires appropriate policies and measures to prevent and mitigate potential impacts.

### **Collision between wildlife and grid infrastructure and panels**

Large-scale solar PV projects are often situated away from energy consumption centres (*e.g.* cities, industrial centres) and therefore require grid infrastructure, including powerlines and substations, as well as roads. The construction and operation of this infrastructure can have negative environmental impacts.

Powerlines and substations connected to solar PV plants often overlap with wildlife habitats or the migratory routes of certain bird species. Birds and other wildlife can collide with or be electrocuted by overhead powerlines and substations, which are key infrastructure for transmitting and distributing renewable electricity to consumers. Collision with and electrocution by powerlines and substations can lead to debilitating injuries to and the death of wildlife, and fenced substations can cause habitat fragmentation and degradation. At the same time, these collisions and electrocution accidents usually cause disruptions to the electricity system, damage to equipment and increased costs for utility companies. They may also increase the risk of wildfires that may result in the loss of property and/or habitats.

Solar PV plants' other impacts on biodiversity include collisions between birds and the panels, as well as the introduction of invasive species during the replantation process. In California (United States), there are reports that ten solar PV plants may be responsible for the deaths of 2.49 birds per MW per year, based on 13 years of monitoring (Kosciuch *et al.*, 2020). Wild animals, including birds and aquatic insects, can mistake the flat surface of PV panels for water and therefore cause maladaptive behaviours (IUCN, 2021). As a comparison, it is estimated that each wind turbine (averaging around 3 MW in capacity) may be responsible for between 4 and 18 bird deaths annually in the United States (Ritchie, 2025). The construction of solar PV plants and the replantation processes carried out after construction can also introduce invasive species, posing threats to local ecosystems.

### **Impacts on landscape and connected cultural heritage**

The deployment of large-scale solar PV plants and their associated grid infrastructure changes the landscape structurally and visually. Concerns may be raised about their negative impacts on aesthetics and cultural heritage.

In Germany and the Netherlands, concerns about landscape change emerged as one of the drivers of non-governmental organisations' (NGOs') and local communities' opposition to renewable energy deployment (Becker *et al.*, 2025). In most cases, originally rural or natural landscapes are seen as an important part of local communities' history or daily life. They can also be connected to aesthetics, recreational services, tourism value and cultural heritage.

The deployment of large-scale solar PV projects can significantly change landscapes and their value for local communities. These potential negative impacts on the landscape and cultural values can provoke opposition from local communities and therefore constitute a major barrier to solar PV deployment. In the United Kingdom, for example, a solar PV project covering 1100 ha of land planned for deployment in rural Devon

raised local residents' concerns about a changed landscape (England, 2025). A comprehensive assessment of impacts on landscape and cultural heritage in the local context can help avoid damage to local landscape and aesthetic values, and therefore increase the social acceptance of renewables.

### Water demand for solar PV plants

Water demand for solar PV plants is another topic under discussion in relation to environmental impacts. Most of the water consumption in solar PV plant operations is used for regular panel cleaning to ensure expected power generation. While the cleaning frequency depends on local weather conditions, technological advancements and increased cleaning efficiency are able to minimise water demand for panel cleaning. However, when deployed in areas facing water scarcity and high water stress for agricultural use, proper planning and careful assessment of solar PV water demand can help avoid further increases in water stress in these areas.

Given these potential negative environmental impacts, future policies for solar PV development would benefit from an integrated perspective that considers their potential environmental impacts. Such a perspective could help determine which measures and solutions can be developed to avoid, reduce or mitigate these impacts and ensure deployment is sustainable. Many countries have adopted the environmental impact assessment (EIA) as a mandatory precondition for renewable project permitting. However, additional efforts are necessary to address remaining gaps, increase the capacity of the related industry, and strengthen the effectiveness of these tools, as well as to conduct a dedicated assessment of unique environmental and biodiversity impacts linked to local contexts (see chapters 4 and 5). If proper policies and measures are in place at the early stages of project planning, the majority of unwanted impacts on nature can be avoided and minimised (see Chapter 3).

## 2.3 POTENTIAL INTERACTIONS THAT CAN BE UTILISED FOR CO-BENEFITS

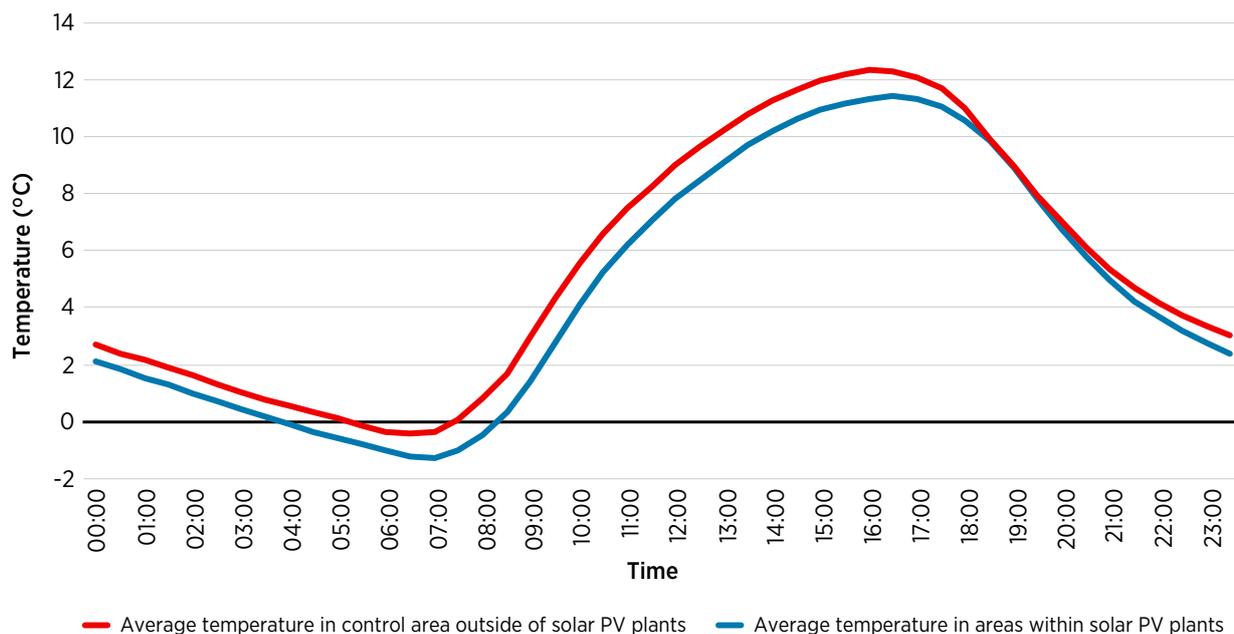
The operation and maintenance of solar power plants usually lasts over 30 years. In this time, they can interact with the local environment in many ways. Some of these interactions can be further utilised, under specific conditions and contexts, to create synergies between solar PV plants and the surrounding environment, and to provide additional ecological services.

Shading from solar PV power plants to the area beneath them plays a fundamental role in driving relevant environmental changes during the project operation phase. A large area of shading covered by solar panels can influence microclimatic conditions, including temperature, air humidity, soil moisture and light availability. In Germany, a study found that solar radiation underneath solar PV panels can be 30% less than in the field without panel coverage (Fraunhofer ISE, 2019). Such a difference in shading can affect the microclimate and other relevant changes in the area, for example, by reducing temperature and water evaporation, among other changes. In the long term, it can alter soil decomposition processes and plant communities beneath the PV panels.

### Reduced ground temperature beneath panels

Reduced solar radiation has been associated with modified microclimatic conditions, notably reduced temperatures (Leroy *et al.*, 2025). During the daytime, part of the solar radiation is absorbed by panels and converted into electricity. As a result, the ground temperature of solar power plants during the daytime (and during seasons when solar radiation is strong) can be lower than that of others without solar panel coverage (see Figure 10). In other words, solar PV power plants can be linked to lower ground temperatures during the daytime (due to reduced solar radiation). In regions with short daylight hours and moderate climates, the temperature difference caused by solar power plants may be negligible. However, in areas with longer daylight hours, the impact of solar panels on ground temperature might be greater than in other regions.

**Figure 10** Example of ground temperature difference within and outside of solar PV plants, 2024



Source: (RCPEIE, 2025).

Note: 1) Data were collected by Research Centre for Plateau Energy Industry and Ecology at solar PV plants in Qinghai Province, China; 2) data show average temperature difference in 2024.

Similarly, solar panels may reduce energy loss at night by reflecting energy emitted from the ground back into the atmosphere. This is proven by multiple studies on solar power plants deployed in agricultural lands or desert areas, where the ground temperature at night (or during seasons when solar radiation is fairly weak) under solar panels can be higher than in areas without solar panels. For example, in northwestern China, monitoring of solar PV plants has shown that they can increase ground temperatures by 10% to 30% during autumn and winter. The ground temperature under solar PV panels can be around 1°C higher than in areas with the same conditions without panel coverage (Tan *et al.*, 2025). Monitoring of solar PV plants in other solar projects also revealed that solar PV plants can make ground temperatures warmer during winter and cooler during summer, both with around 0.5-0.6°C difference (Zhao *et al.*, 2024).

The same impact was also observed in Europe and the United States. Monitoring by experts of a 46 MW solar PV plant in Portugal showed that solar PV plants can slightly reduce (by around 1°C) the ground temperature in summer and increase it during winter (Hurduc *et al.*, 2024). When solar panels cover a large area, such as hundreds of hectares, the airflow beneath them, combined with shading, can provide a steady cooling effect, even with negligible differences of around 1°C. In the United States, observations from a pilot solar panel plant, combined with agricultural activities at Oregon State University, showed a 0.3°C temperature difference beneath the solar panels compared to control areas without solar panels (Hassanpour Adeh *et al.*, 2018). Similarly, in Arizona (United States), shading by solar PV projects reduced daytime temperatures and increased night-time temperatures (Pigott, 2019).

### Reduced water evaporation

Water evaporation can be reduced in solar PV power plants. In China, large-scale solar PV plants deployed in arid and desertification areas have been shown to reduce ground evaporation by more than 24% during the summer season (July and August) (SPIC, 2025). In Germany, solar PV plants have also been observed to reduce water evaporation by 9-22% (Ludzuweit *et al.*, 2025). In the case of vegetation management or agricultural activities under the solar PV panels (see Chapter 3), reduced water evaporation results in more efficient water use for plantation-related activities below the panels. In arid areas, such effects can be utilised as co-benefits to reduce water stress.

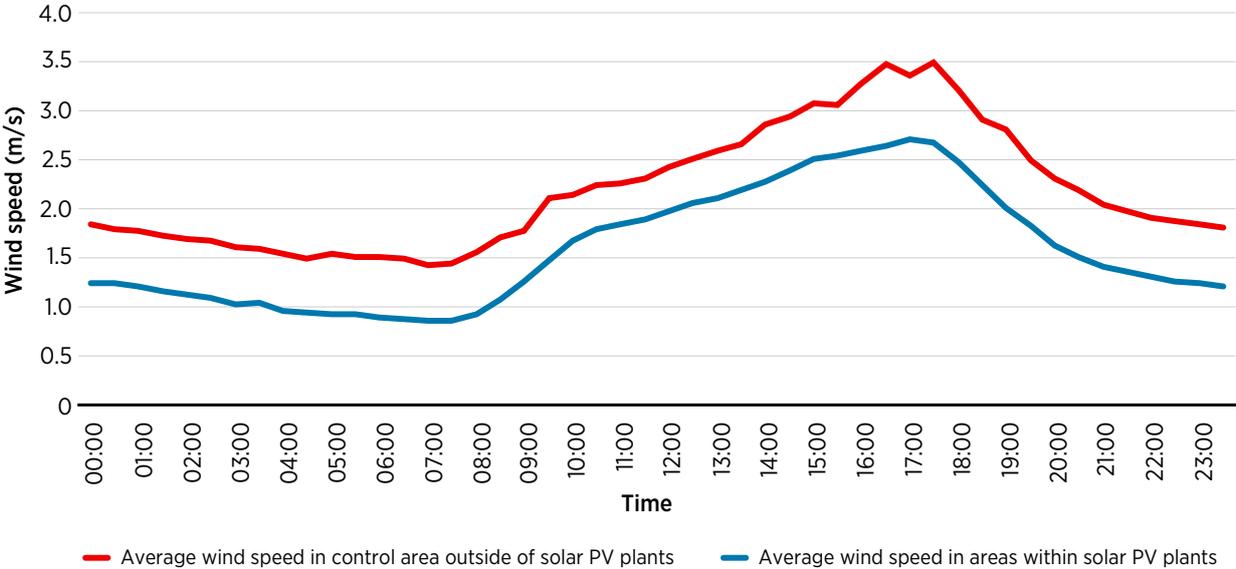
In the United States, a solar PV plant combined with biomass production showed the same amount of water can produce six times more biomass in areas covered by solar panels than in areas without them (Hassanpour Adeg *et al.*, 2018). In other words, with the same rate of vegetation coverage, land under solar panels may need much less water consumption to reach the same coverage. In Italy, maintaining the same level of plant coverage under the solar panels would require a 20% reduction in water consumption compared to other practices (Enel, 2023). In the case of solar PV projects combined with agricultural activities, reduced water evaporation results in more efficient irrigation and reduced costs. In the United Republic of Tanzania, a pilot project combining solar PV plants and crop production revealed a 13.8% reduction in water demand for crop irrigation (Randle-Boggis *et al.*, 2025). Monitoring of solar PV plants in the United States also revealed that solar PV plants can reduce water demand for vegetation growth during dry seasons (Rahman *et al.*, 2023).

However, solar panels can block rainfall from reaching the ground beneath them and increase the risk of soil erosion due to concentrated runoff from the sloped panels. Properly designed projects and additional measures, such as rainfall gutters attached to panels or planted vegetation for soil conservation, are needed to help to mitigate these relevant impacts.

### Reduced wind speed beneath solar panels

Large-scale solar PV plants can reduce ground wind speed and direction. In Qinghai Province (China), the wind speed below panels of large-scale solar plants (a GW-level project) was reduced by 20% to 40% compared to similar areas without solar PV power plants (See Figure 11). The main reason for this reduction is that the solar panels deployed on the ground increased the resistance to airflow, thereby reducing the wind speed near the ground. The wind direction is also observed to have changed in the plant. In a pilot project based at Oregon State University (United States), the wind speed beneath solar panels (below 1.2 metre (m) height) was reduced by 24% to 38% compared to the control area without solar PV installation (Hassanpour Adeg *et al.*, 2018).

**Figure 11** Example of wind speed difference within and outside of solar PV plants, 2024



Source: (RCPEIE, 2025).

Notes: 1) Data were collected by Research Centre for Plateau Energy Industry and Ecology at solar PV plants in Qinghai Province, China; 2) data show average wind speed difference in 2024. m/s = metre per second; PV = photovoltaic.

Reduced wind speed itself has a neutral impact. In areas where high wind speed is a key driver of sandstorms and desertification expansion, a reduced wind speed can be a lever to reduce these risks, complementing other dedicated sandstorm control measures (see Chapter 3).

## Increased soil moisture and reduced soil temperature

Solar PV plants can increase soil moisture due to reduced radiation and evaporation. This has been observed over multiple years of monitoring solar PV plants in China, Europe and the United States. In northern China, several large-scale solar PV plants are deployed in arid areas. Over five years of monitoring (2019-2024) of environmental indicators by a subsidiary institute under China's State Power Investment Corporation Limited (SPIC) found that soil moisture under solar panels increased by 15%. In the United States, solar panels installed at the University of Arizona increased soil moisture by 15% compared to the control area without solar panels (Pigott, 2019). Another pilot solar power plant at Oregon State University showed a 20% increase in soil moisture at a 20 centimetre (cm) depth after seven months of operation. Soil moisture enhancement can be much larger (a 39% increase compared to the control area) at a depth of 40 cm (Hassanpour Adeg *et al.*, 2018). In the Midwest region of the United States, solar PV plants have also increased sediment retention by over 95% and water retention by 19% (Leroy *et al.*, 2025).

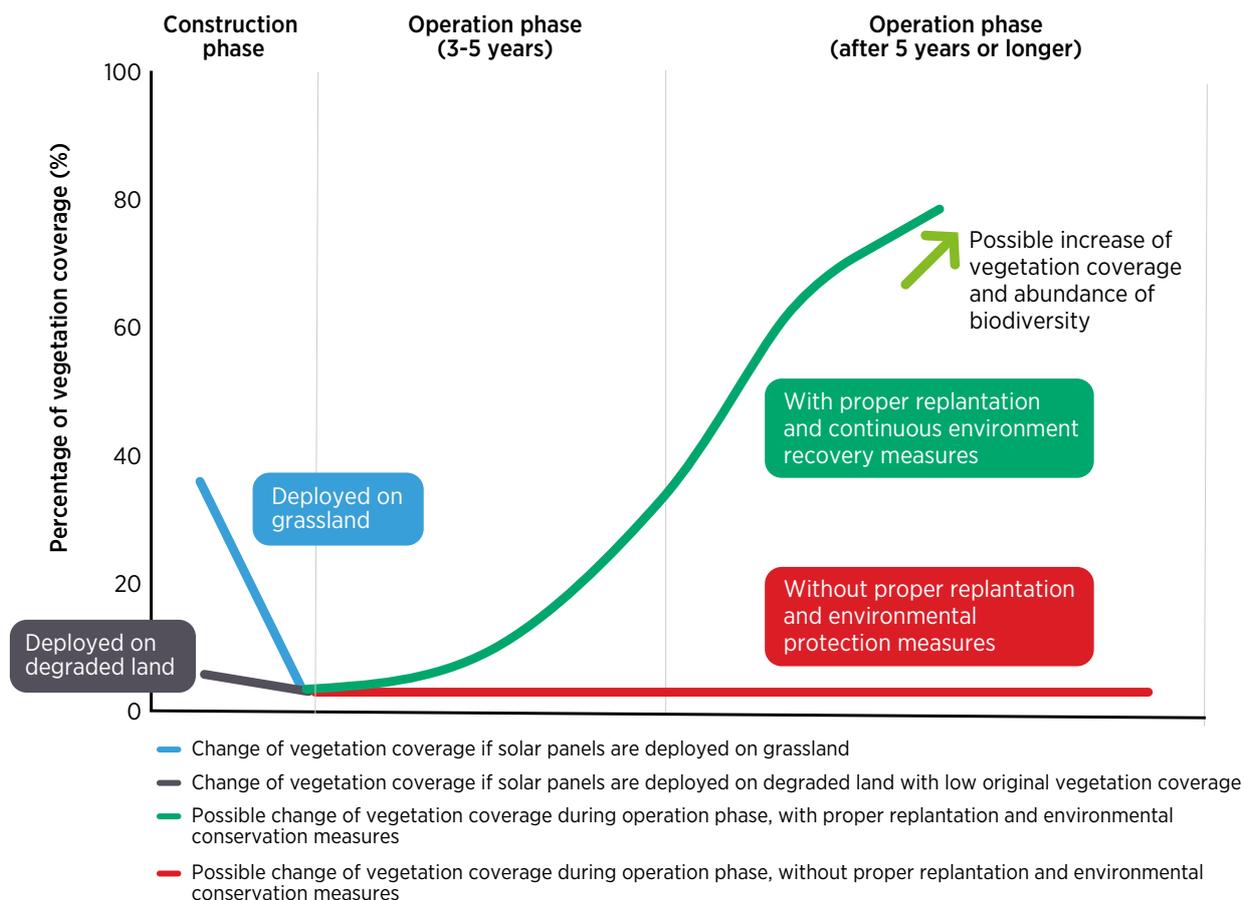
Soil temperature can also be reduced. In Germany, it has been observed that soil temperature can be reduced in solar power plants (Yang *et al.*, 2017). In China, solar PV plants can reduce the soil temperature by 20% compared to those without panel coverage (Yang *et al.*, 2017). In dry and semi-dry areas, increased soil moisture can have positive impacts on soil health and vegetation growth. Similarly, in areas where extreme-high temperatures are frequent and threaten vegetation growth, reduced soil temperature can be helpful.

## Changed soil quality and vegetation coverage

Years of solar operation may improve soil quality (Tian *et al.*, 2024). Monitoring of soil from solar power plants in Shaanxi Province (China) revealed that, alongside vegetation recovery, soils under solar panels have a higher share of organic matter, phosphorus and potassium, all of which are important nutrients for plant growth. Observations of solar power plants in Qinghai Province showed increases of over 80% in organic matter and nitrogen. Similar impacts have also been confirmed through studies on solar power plants installed in various locations. These changes in soil quality may be linked with the fact that shading from panels can affect the decomposition process, mixed with changed temperature and moisture, and other effects (Shang *et al.*, 2025).

In some contexts, vegetation coverage can be enhanced by improved soil conditions and temperatures. Years of monitoring solar PV projects deployed in Gonghe County (China) showed that vegetation coverage on land where panels are installed has increased significantly from less than 2% to over 55% in a decade. The same vegetation changes have also been observed in Dengkou County (China), where a 270 MW solar PV project increased vegetation coverage from less than 8% (given this is an arid area threatened by desertification) to 77% in less than ten years (SPIC, 2025). However, it is worth noting that in areas where land clearing reduces vegetation, it can take two to three years or longer for the soil and vegetation to recover to their original levels (see Figure 12).

**Figure 12** Possible impacts on vegetation during solar PV plants' construction and operation



In the United States, solar PV plants at Oregon State University have shown that the weight of dry biomass (semi-arid pasture) harvested in solar farms was 90% more than that harvested in a control area (Hassanpour Adeg *et al.*, 2018). This resulted from improved vegetation growth in solar PV plants. In California, observations on two solar PV projects found that plants under solar panel arrays have higher water and nitrogen content and lower non-digestible fibre content than plants in areas without solar PV plants (Gersoff and Sistla, 2022). In the United Kingdom, solar PV plants have been shown to enhance local flora in the areas where panels are installed (Copping *et al.*, 2025).

### Impacts on freshwater and marine systems

Solar PV panels can be deployed on floating foundations over freshwater and marine water bodies, such as oceans, lakes, reservoirs, ponds and canals. Floating solar PV projects offer unique opportunities for areas with limited land but large water surfaces. They can also affect various factors of the water ecosystem.

Floating solar PV projects can reduce water evaporation and surface temperatures by reducing the amount of solar radiation reaching the water surface. It is estimated that solar PV deployed on the water surface can reduce water evaporation by 25% to 70%, depending on local climate conditions (Nisar *et al.*, 2022). In the United States, a 38 MW floating solar PV plant is deployed in North Carolina, covering over 1 000 hectares of water area. It is estimated that over 30 000 cubic metres of water evaporation were avoided throughout 2020 by covering the water surface with solar panels (Hussain *et al.*, 2024).

Floating solar PV projects can also reduce water temperature. In Fuqing City, China, a 20 MW solar PV project is deployed on aquacultural ponds. A study showed that PV reduced solar radiation at the pond's surface by around 90%, resulting in an average reduction in water temperature of 1.5°C and a substantial decrease in light intensity (Song *et al.*, 2024).

Floating solar PV systems can alter water quality and affect the aquatic ecosystem, with long-term effects that can be positive or negative. The change of solar radiation reaching the water surface may result in a notable increase in dissolved oxygen concentrations of approximately 8-24%. PV panels also reduce the concentration of labile phosphate, active silicate, total nitrogen, total phosphorus and total organic carbon. All these changes and impacts on the water ecosystem can affect living species. One identified impact is that floating solar can control algae growth. In India, solar PV panels are deployed on top of irrigation canals to provide power for the agricultural irrigation system. The panels also reduced water evaporation and controlled algae growth in the water, which can clog water pumps and cause damage to irrigation systems and the local community (Sunder, 2020).



## CHAPTER 3

# EXISTING SOLUTIONS AND PRACTICES FOR SOLAR INDUSTRIES TO PROMOTE SUSTAINABLE DEPLOYMENT

## 3.1 INTEGRATED PROJECT DESIGN AND PLANNING

The design, planning and management of a renewable energy project play a decisive role in shaping its environmental impacts and co-benefits. While a properly planned and managed solar PV project can avoid most significant negative impacts and bring various co-benefits to nature, poor planning can not only cause negative environmental impacts but also create tension with local communities, which can be a barrier to solar PV development. Therefore, integrating environmental and biodiversity considerations into renewable energy project planning remains key to avoiding unwanted environmental impacts. Some tools and methods can secure such integration, including tools to support site selection, biodiversity sensitivity maps and risk screening tools to assess biodiversity risks in specific areas (Bennun *et al.*, 2021a).

Project developers should apply a mitigation hierarchy, including avoidance, minimisation, restoration and offset. Among the available options and measures, most environmental impacts can be avoided by adopting appropriate tools and practices at the early stage of project planning and design. Therefore, integrating environment and biodiversity considerations into the early planning stage should be the first priority for project developers.

### Environmental impacts mitigation hierarchy

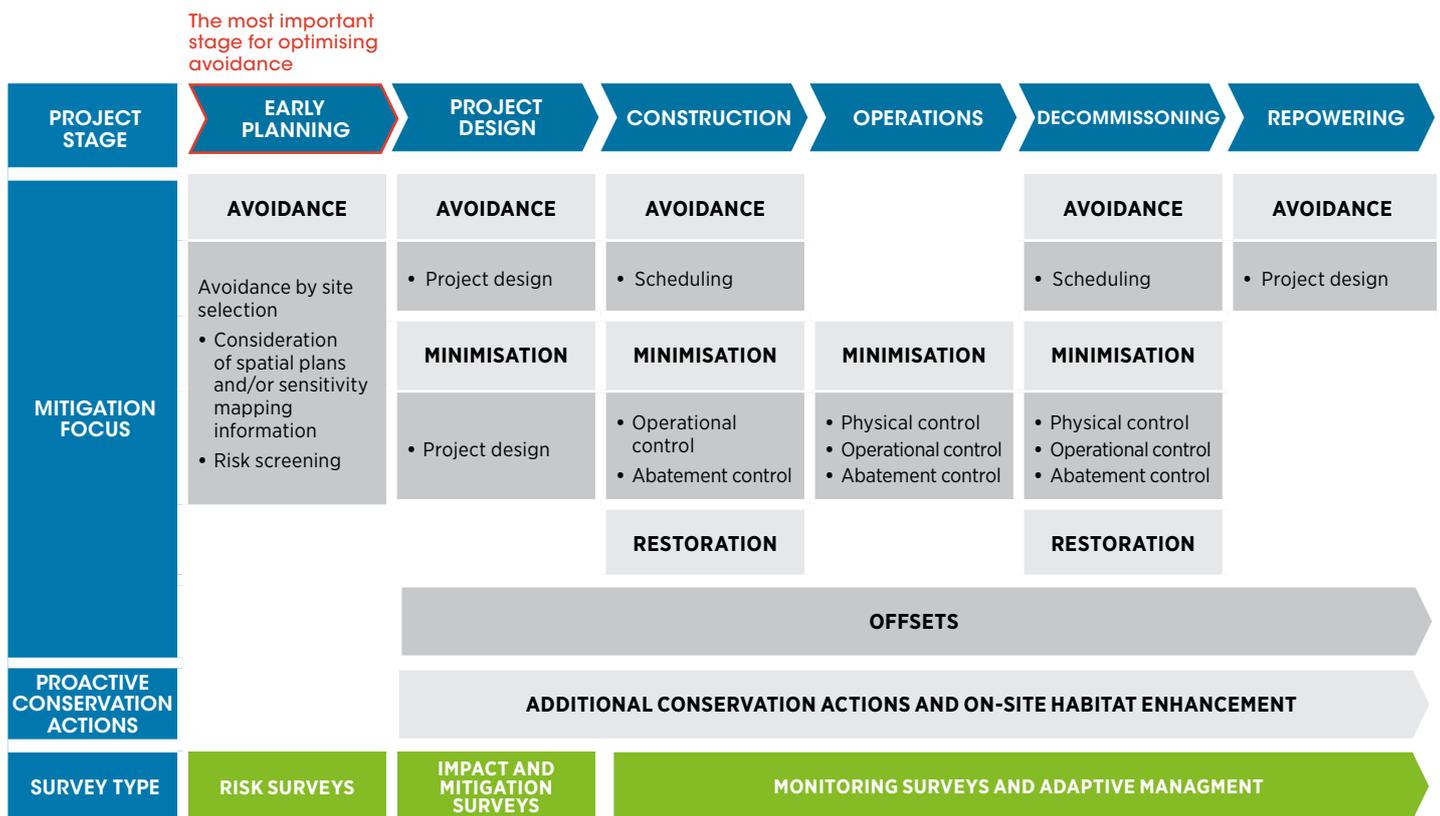
Integrating environmental and biodiversity considerations into the spatial planning process can be the most effective way to avoid most unwanted environmental impacts. IUCN and the Biodiversity Consultancy proposed an approach with a mitigation hierarchy of stages to properly manage the potential impacts of solar PV plants (see Figure 13) (Bennun *et al.*, 2021b). This mitigation hierarchy provides stakeholders with a framework to address the negative impacts of project development.

Of the four steps in the mitigation hierarchy – avoidance, minimisation, restoration and offset – avoidance is the most important step. It requires proper site selection (to avoid locations in high-risk areas), integrated project design (to integrate measures for conservation of wildlife and habitat), and scheduling of construction (to avoid disturbing wildlife breeding and nesting seasons) to anticipate and prevent possible impacts. When impacts cannot be fully avoided, measures should be applied at every project stage to minimise their intensity, duration and extent. During construction and decommissioning, some damage cannot be completely avoided or fully minimised; restoration measures are necessary to restore environmental features and biodiversity components. Offsets<sup>2</sup> are measures to compensate for significant residual impacts that cannot be avoided, minimised or restored. They should be considered only as a last resort to address residual impacts after all other options have been exhausted. Otherwise, offset measures may be linked with greenwashing concerns. Within the mitigation hierarchy, early planning is the most important stage, optimising the avoidance of most of negative impacts.

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<sup>2</sup> According to IUCN, there are some circumstances in which biodiversity offsets are not feasible or appropriate. This happens when technical requirements for offsetting may not be met (e.g. it is not possible to protect or restore the target species or ecosystem elsewhere) or an offset is theoretically possible but the risk of failure is very high. In these circumstances, offsets cannot be used, meaning that the project as designed should not proceed (Bennun *et al.*, 2021b).

**Figure 13** The mitigation hierarchy across the project development cycle of renewables



Source: (Bennun *et al.*, 2021b).

Prioritising deployment on degraded land, or on disturbed areas where the environment has been altered by construction or mining activities, can be an important approach. Solar PV plants are often suggested for deployment on disturbed and degraded land (e.g. abandoned mines, landfills, or land polluted by chemicals or oil). On these disturbed and degraded lands, local vegetation and animals are often removed or disturbed by historical construction or mining activities. Deployment of solar plants on these lands would cause less damage to biodiversity than deployment on natural lands. Some of these degraded lands, such as mining sites, may have transmission access and other energy infrastructure nearby, including roads and water infrastructure, which could help offset infrastructure costs for plant developers (TNC, 2023). Further, in desertification areas with lower biodiversity values or facing threats from land degradation, deployment of solar PV may also help control the degradation process.

### Integrating environment and biodiversity considerations into project design and planning

Properly designed solar PV plants that take environmental impacts into consideration can minimise unwanted impacts and realise co-benefits in a cost-effective way. Siting or selecting the project location remains one of the most important steps to achieve this.

For solar PV deployment, an EIA is usually a mandatory step during the permitting and approval process. As an analytical process to examine the possible environmental impacts of a project, EIAs have been widely adopted by major development banks and countries with larger installed capacities of solar PV plants to help identify potential environmental impacts and measures to mitigate them.

For major solar PV companies, EIAs are also a key component of their reporting on performance related to ESG. However, in many cases, existing EIA policy cannot capture all possible impacts on wildlife and biodiversity in a specific and complex context. An early understanding of potential sensitivity is beneficial for developers,

as it allows them to identify possible issues before physical construction begins (IUCN, 2024). In this way, solar PV project companies can ensure that appropriate mitigation measures are factored into project design from the outset. This understanding also allows renewable energy projects to avoid and minimise possible encounters with wildlife and unwanted impacts on nature.

Overall, the siting of solar PV plants should follow some general principles, such as avoiding protected areas with strategic ecological or biodiversity value or high-productivity farmland. New solar projects may also be deployed on disturbed land, such as degraded land or abandoned mining sites. In countries with a large area of degraded land or facing threats of desertification, the deployment of PV projects in these areas can also be utilised to accelerate the recovery of ecosystems and control desertification and sandstorms. The Coalition Linking Energy and Nature for Action (CLEANAction) and IRENA Coalition for Action have developed six key principles for the siting and permitting of nature-positive energy projects (see Figure 14). These principles have called for emphasising proactive efforts to conserve, restore and enhance ecosystems, as well as engaging local actors through participatory processes to ensure public support, shared benefits and the integration of local knowledge (IRENA Coalition for Action, 2025).

**Figure 14** Six principles for nature-positive energy siting and permitting



Source: (IRENA Coalition for Action, 2025).

Spatial planning and zoning tools for identifying biodiversity risks and values in targeted renewable energy site areas are important for helping developers avoid high impacts. Given environmental conditions and biodiversity, many existing mapping tools can help solar project developers identify potential interactions and impacts on the local environment and biodiversity at an early stage in the planning process. These existing tools usually use geographic information systems (GIS) to collate, analyse and display spatial and geographic data as the basis to assess ecological communities sensitive to the construction, operation and maintenance of solar PV plants. An example of this is Spain’s national-level accessible biodiversity mapping, which is provided to stakeholders and concerns not only protected areas but also the presence and distribution of bird species. These mapping tools integrate data on bird species and their habitats, wildlife corridors and areas of importance for endangered species recovery plans, among other categories of sensitivity.

Many other tools have emerged to help developers to integrate environmental considerations and biodiversity into site selection for solar PV plants. For example, the Integrated Biodiversity Assessment Tool is a mapping and reporting tool that integrates access to three global biodiversity datasets: the IUCN Red List of Threatened Species, the Database on Protected Areas, and the World Database of Key Biodiversity Areas. This tool can help solar PV developers and planners understand the biodiversity situation in targeted areas, including species richness – measured by the number of species present at a given location – and the relative importance of that location for the species (IBAT, 2025). These tools can help project developers and stakeholders to identify the best locations with minimal impacts. However, most of these platforms developed by international organisations cannot provide tailored recommendations for solar projects in every country or region, which should be complemented by onsite assessments by local experts.

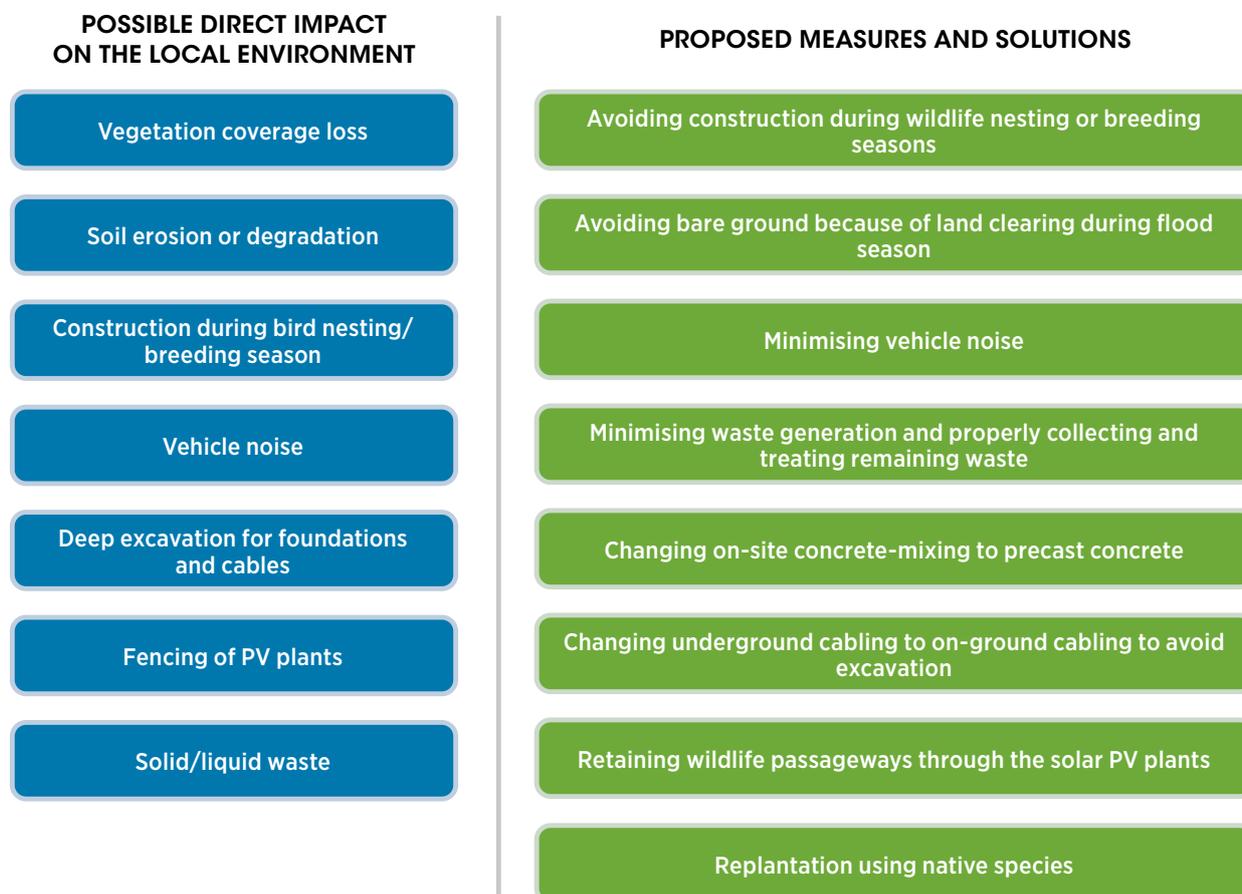
A biodiversity sensitivity map or similar tool can help developers and stakeholders assess risks to biodiversity and nature in specific areas, enabling them to identify areas with low risk to the local environment and biodiversity for project deployment. BirdLife International, one of the largest international conservation organisations, developed a tool called Avistep to provide a detailed spatial assessment of avian sensitivity to various types of energy infrastructure, including wind farms, solar PV facilities and overhead power lines (López and Allinson, 2022). This tool can support project developers in site-level screening and evaluation of potential biodiversity impacts, thereby helping developers identify low-risk sites for future solar PV plant selection. However, such a tool is available only in a limited number of countries, including Kenya, Egypt, Thailand, Viet Nam and a few others. More effort is needed to make it available to more countries and regions.



### 3.2 IMPACT MITIGATION DURING CONSTRUCTION

Disruption to the environment and biodiversity during solar PV project construction can be avoided and mitigated through the adoption of environmentally friendly practices (see Figure 15).

**Figure 15** Measures to avoid and minimise impacts during the construction process



A careful assessment of construction timing can help avoid major threats to wildlife by avoiding construction during the breeding seasons of local wildlife or flyways. It should also avoid seasons when rainfall can increase the likelihood of soil erosion or flooding in areas after land clearing and before vegetation recovery measures are implemented. During construction, onsite human activities and vehicles should also minimise waste generation and pollution, including wastewater and noise from vehicles. For example, concrete foundations remain one of the main options for mounting solar PV projects. Changing from onsite concrete mixing to precast concrete, or from concrete foundations to screw pile foundations, can avoid most of the environmental disturbance – including noise, dust and water pollution – of the mounting process.

Revegetation is another important practice to mitigate environmental impacts. Vegetation coverage is often affected during construction due to land clearing. If appropriate recovery measures are implemented to support environmental recovery, vegetation can be restored to a level similar to that before PV plant deployment. After that, local environmental and biodiversity conditions may improve to a higher level than before. How vegetation is maintained during operations has a significant impact on biodiversity outcomes. Further, if solar PV plants are deployed on degraded land and accompanied by restoration measures, opportunities can be utilised to enhance the local biodiversity.

Planned corridors and passages for wildlife present another important mitigation measure. In North Carolina (United States), large solar farms (over 40 ha) are advised to retain unfenced wildlife passageways through the solar facility to connect potential wildlife habitat. Such passageways should be 30 m wide for ground-dwelling birds and reptiles and 45-90 m wide for larger mammals, such as deer and bobcats (TNC, 2023). If properly designed based on an assessment of local wildlife, permeable fencing around solar PV plants could offer another option to support wildlife movement.

An increasing number of solar companies have started employing other environmentally friendly practices. For example, solar power plants can switch from deep excavation to on-ground cabling, thereby avoiding land impacts associated with deep excavation. For major solar PV companies, it has become increasingly popular to replace the PV foundation process with alternatives that have less impact. Previous practice involves excavating to bury the concrete foundation. Changing to screw pile foundations can avoid a large area of excavation and its damage to the land (Zhou *et al.*, 2019).

### 3.3 SYNERGISTIC OPERATION AND MAINTENANCE

#### Agrivoltaics

Solar PV panels deployed above plants significantly impact several key factors affecting plant growth and reproduction: temperature, direct sunlight, humidity and water. These factors are also key considerations for agricultural activities. A careful assessment of impacts indicates that combining solar PV plants with agricultural activities can create co-benefits.

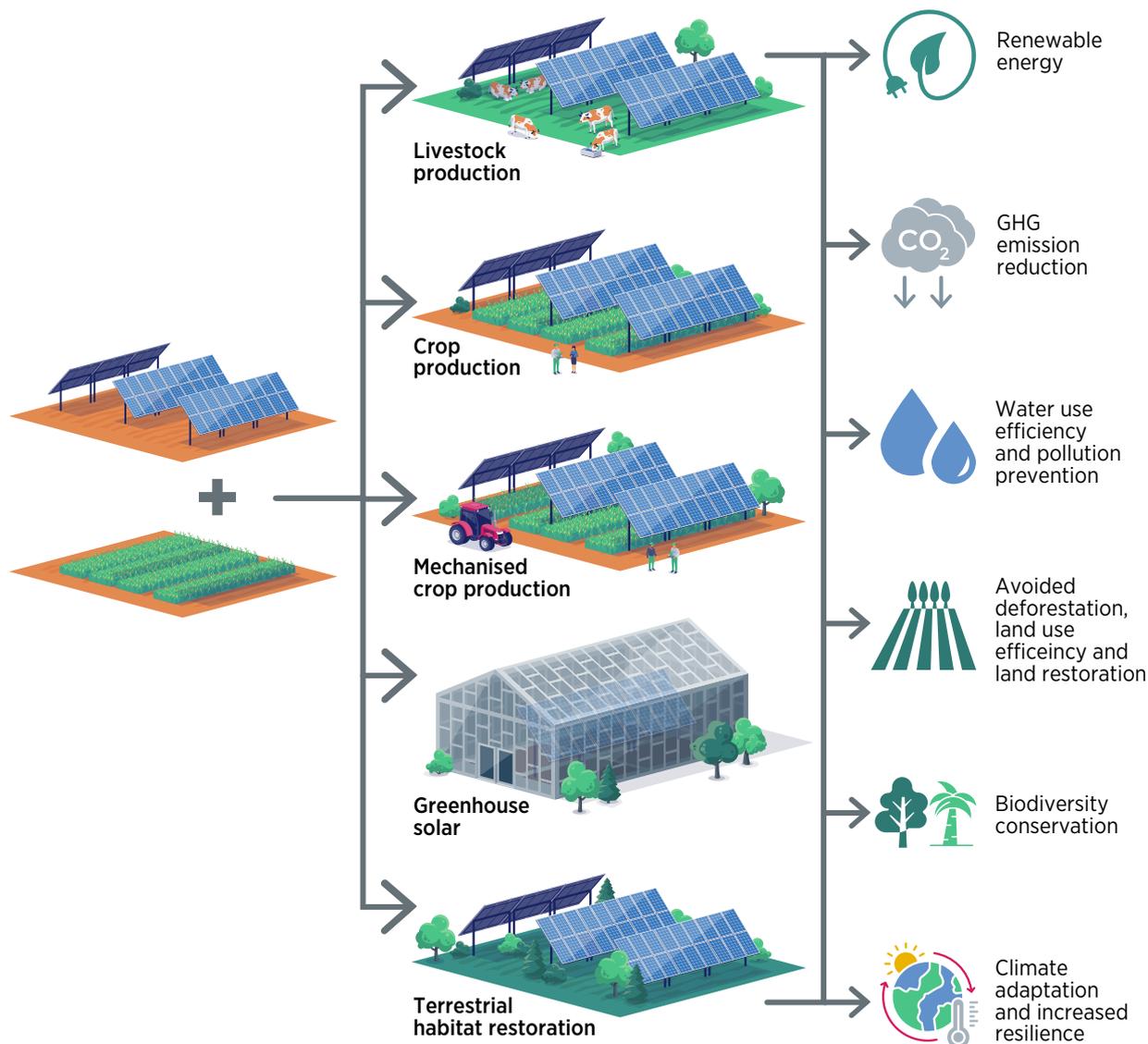
Combining solar PV plants with agricultural activities is usually called agrivoltaics,<sup>3</sup> which involves integrating solar PV plants and agricultural activities on the same land, including the production of crops, vegetables, fruits and herbs for medical purposes (see Figure 16). This integration allows both renewable electricity and agricultural production to be harvested on the same land. Agrivoltaics is referred to by many other terms, including “agrisolar” and “dual-use solar” (Lidoro, 2022; Macknick *et al.*, 2022). However, it is worth noting that agrivoltaics should be based on environmentally friendly agricultural practices<sup>4</sup> and utilise the co-benefit to the environment and its added values to meet human food needs (McCall *et al.*, 2023).



<sup>3</sup> In some markets, agrivoltaic pilot projects comprise less than 1 MW.

<sup>4</sup> Non-environmentally friendly agricultural practices include overuse of synthetic fertilisers and pesticide, among other practices.

**Figure 16** Potential co-benefits of integrating solar PV and agriculture



Source: (Chirinda *et al.*, 2024).

Agrivoltaics can benefit agricultural activities in multiple ways, including reduced irrigation water demand; higher crop survival rates; and increased crop, fruit and vegetable productivity. Solar PV combined with agriculture can reduce irrigation water use by decreasing evapotranspiration from PV panel shading (see Chapter 2). Water consumption for agricultural irrigation can be reduced by 20-30%, as demonstrated by monitoring three operational project sites in France, Greece and Spain (Solar Power Europe, 2025). In the United Republic of Tanzania, solar PV plants are combined with local crop production in a pilot project supported by the University of Sheffield. The bean crop showed a 60% higher survival rate under panels compared to conventional practices, indicating improved crop resilience in agrivoltaics under local climatic conditions. In agrivoltaic projects, the impact on crop and vegetable productivity depends on local climate and plant types. Crops requiring high levels of sunlight – like wheat, corn and rice – have shown mixed yields depending on the growing season. In contrast, leafy greens like lettuce and spinach and root crops like potatoes, radishes, beets and carrots have shown increased yields (Chirinda *et al.*, 2024).

Agrivoltaics have increased agricultural productivity in Europe, India and the United States. In the United States, a demonstration project in Arizona showed that some fruit and vegetable production (e.g. chitepin, tomato) was two or three times greater than that under the same climate conditions but without solar panels (Pigott, 2019). In Germany, a study found that celery yields 15% more under solar panels than in control areas, and winter wheat can increase productivity by 3% under solar panels. In Italy, agrivoltaics can yield

20% to 60% higher productivity in agricultural areas than in areas without solar panels, depending on the type of crop. Forage used to feed cattle and planted between rows of panels in Italy increased by 40% and strawberries increased by 14% under panels and 18% between rows. Meanwhile, harvests of Italian aubergines and peppers increased by 30% and 60%, respectively (Enel, 2023). A pilot agrivoltaic project in Maharashtra, India, showed that shading effects and reduced evaporation can result in up to 40% higher yields for tomato and cotton crops (Fraunhofer ISE, 2019).

In areas lacking access to electricity, agrivoltaic systems can be combined with solar-powered irrigation, enhancing the agricultural productivity and resilience of smallholder farmers in dry areas. These systems grant farmers opportunities to irrigate crops during dry seasons. In some cases, additional solar-powered irrigation can extend growing seasons from three to six months, thereby significantly increasing agricultural productivity.

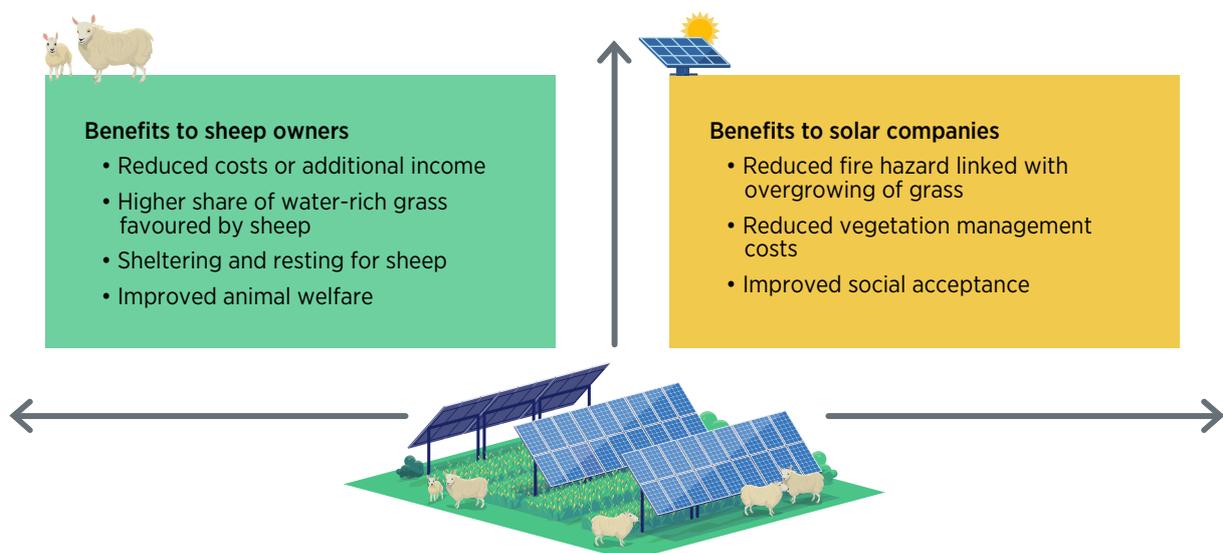
Agricultural solar PV plants require modified designs and installations to enable the operation of agricultural activities and machinery. These modifications need to be based on local crop types, landforms and agricultural practices. In the European Union and United States, industrial associations and research institutes have developed guidelines for industrial stakeholders. However, in most other markets, developers may face barriers related to a lack of experience or increased installation costs (see Chapter 4).

### Solar grazing

Since solar panels can result in additional vegetation growth that needs controlling, combining solar PV plants with grazing livestock (e.g. sheep, goats, cattle, poultry, etc.) can also bring co-benefits.

Sheep grazing combined with solar PV operation has been a win-win practice for many solar PV plants (see Figure 17). Usually, vegetation in solar PV plants needs periodic management to prevent overgrown plants from blocking panels or creating a fire hazard during the dry season. Traditional vegetation management options, including herbicides and mowing, are neither environmentally friendly nor cost-effective. Sheep grazing has therefore been used to manage vegetation at solar plants. In Gonghe County (China), SPIC-owned power plants have signed agreements with 16 farmers to allow these farmers to herd over 600 of their sheep in the solar farms since 2015 (Zhang, 2024). In the United States, the cost of sheep grazing (USD 279/ha/year) for solar farm vegetation management is lower than the cost of mowing (USD 299/ha/year) or herbicide (USD 724/ha/year) (Stewart *et al.*, 2025).

**Figure 17** Potential co-benefits of solar grazing



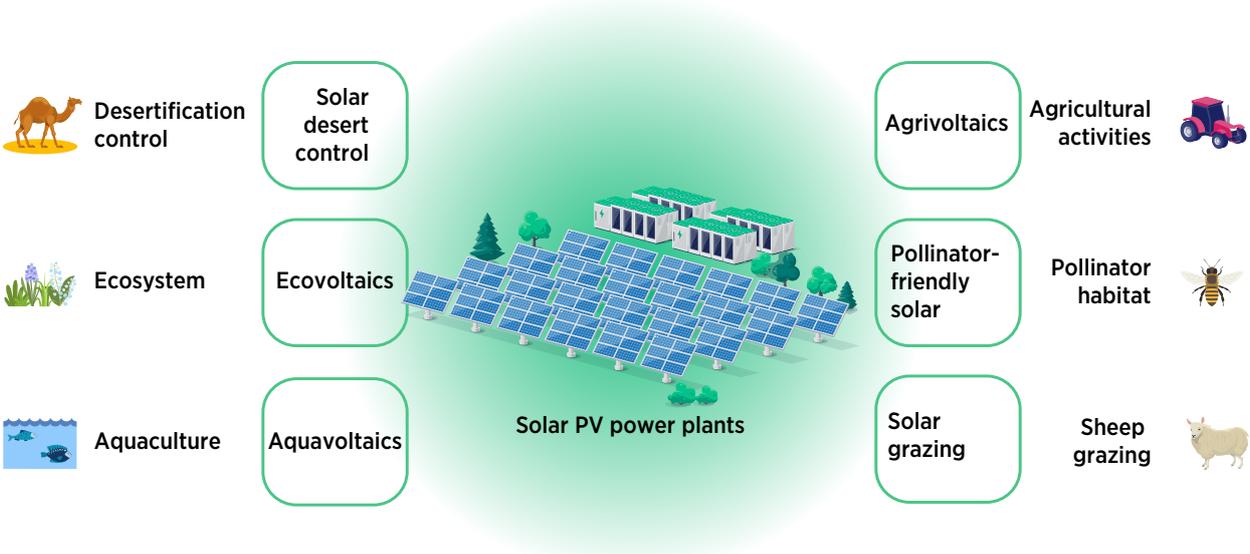
Grazing under solar panels can also benefit farmers because the vegetation beneath them can change over time, making it more favourable to cattle and increasing meat and milk production. Such benefits have been proven based on monitoring of indicators from solar power plants in China and the United States. In the United States, due to changes in moisture, one type of grass (*Alopecurus*) with a higher water content, a readily eaten texture and a preference among livestock has increased from 7% in the control area to 50% in a solar PV plant. This means that grasses favoured by cattle can have a significantly greater presence due to the solar PV plants (Hassanpour Akeh *et al.*, 2018).

In areas with high solar radiation and air temperatures, solar grazing can also improve livestock welfare, as these panels can protect the animals from heat.

**Solar for ecological conservation**

By considering the impact on nature in their operations and management, solar PV plants can also contribute to biodiversity enhancement, including increased species richness and populations of birds and pollinators (see Figure 18). In the United Kingdom, surveys indicate that solar PV plants can significantly improve local biodiversity. When grass around the solar panels is not frequently cut or grazed (to keep it short) during summer (so that it allows taller grass and the presence of wildflowers), solar PV plants can host six times as many plant and animal species as other arable farmland. In particular, bird abundance in solar farms can also be double that in arable land (Copping *et al.*, 2025). This observed biodiversity enhancement is mainly linked to improved structural heterogeneity in solar PV plants, which can further enhance biodiversity and therefore attract more insects and birds.

**Figure 18** Terminologies related to solar PV plants’ co-benefits with the local environment and biodiversity



Pollinators, such as butterflies and bees, can be key indicators of ecological conservation and play important roles in agricultural activities. In the last several decades, they have experienced a significant decline due to threats from insecticides, invasive species, parasites, diseases and climate change (Bramen, 2020). Properly managed solar PV plants can create a suitable habitat for pollinators. In the United States, the planting of pollinator-friendly vegetation under solar PV plants has been shown to contribute to a threefold increase in pollinator supply compared to areas without panels (Leroy *et al.*, 2025). In addition, the increased abundance and diversity of native pollinators could improve the services these organisms provide for pollination of nearby agriculture and the whole ecosystem, including the improved habitat of birds. In Germany, for example, pollinator abundance in agrivoltaic projects increased by 33% to 88% compared to areas without panels (Ludzuweit *et al.*, 2025).

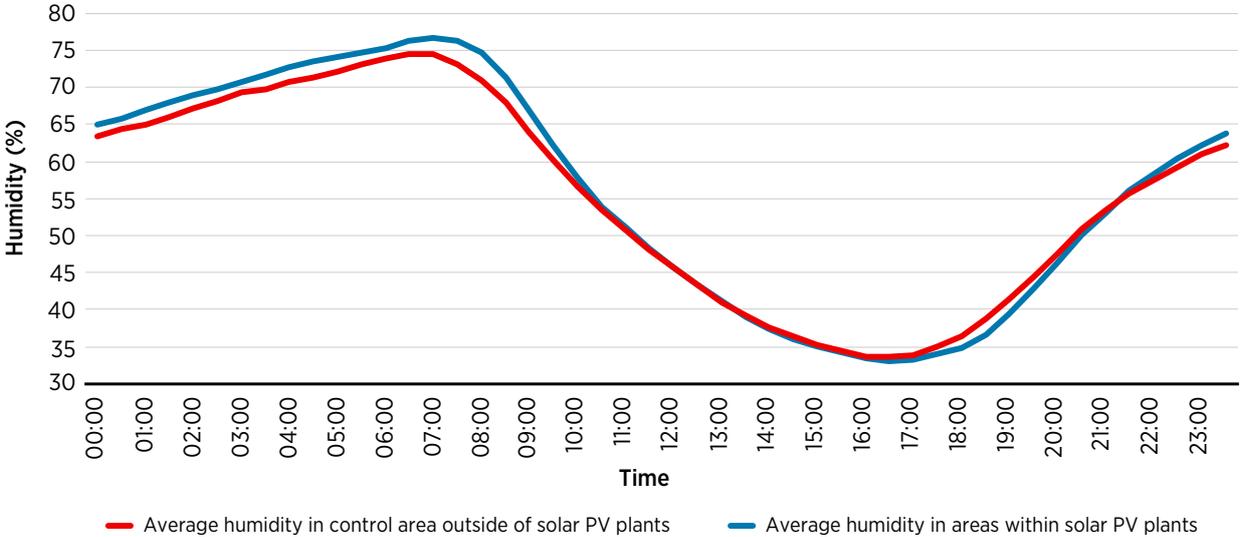
**Solar for restoration of degraded land and the control of desertification**

Multiplying impacts on reduced evaporation, moderated temperatures and improved soil conditions, large-scale solar PV plants may help restore degraded lands, including areas affected by desertification, abandoned mining sites and brownfields.

While deserts can have significant value to the ecological system and specialised biodiversity, the desertification process is usually linked to land degradation. Most of these lands were previously used for agricultural activities, pasture or forestry but have become degraded due to unsustainable practices. Degraded lands in arid areas can cause dust and sandstorms driven by strong winds. When solar PV projects are deployed in areas affected by land degradation, desertification and sandstorms, they may provide additional co-benefits by restoring degraded land, combating desertification and controlling sandstorms.

In dry areas where degraded land is affected by desertification, high solar radiation and temperatures have significantly threatened the growth of vegetation and the biodiversity supported by these plants. When utility-scale solar panels are deployed in these areas, the temperature below the panels can be slightly lower, and humidity and soil moisture can increase. These factors are more likely to enable plant growth or recovery when combined with the condition of the water supply. Changes in wind speed are a key consideration for preventing desertification and sandstorms. Reducing wind speed at solar power plants may slow desertification in areas covered by solar panels. This can be further strengthened by the reality that ground vegetation below the solar panels may increase when soil conditions change and water is irrigated during regular panel cleaning. Combining all these factors, solar PV panels may play a crucial role in controlling desertification.

**Figure 19** Example of humidity difference within and outside of solar PV plants, 2024



Source: (RCPEIE, 2025).

Notes: 1) Data were collected by Research Centre for Plateau Energy Industry and Ecology at solar PV plants in Qinghai Province, China; 2) data show average temperature difference in 2024. PV = photovoltaics.

Areas suffering from desertification and frequent sandstorms may benefit from these potential benefits, supported by carefully assessed impacts on local biodiversity and ecosystems. In China, an 850 MW solar PV plant (which had expanded to 2.2 GW by 2025) was developed in a degraded area threatened by desertification in Gonghe County. The operation of solar PV plants in this area has had a significant impact on vegetation and biodiversity, evidenced by continuous monitoring since 2015. Linked to the solar PV deployment, the area's overall annual average air humidity has increased by 3% during the morning (See Figure 19). Soil temperature below 20-40 cm has decreased by about 17%, and soil moisture at 10-50 cm under solar panels (around 9%) has doubled compared to areas without panels (around 4%) (Zhou *et al.*, 2019). Furthermore, the solar panels reduced wind speed by 53% in the solar PV plants. Another comparison of satellite images from 2011 to 2018 found that 30% of the solar PV plants (covering approximately 102 square kilometre (km<sup>2</sup>) of degraded and desertification areas) deployed in northern China have shown significantly improved vegetation growth and coverage (Xia *et al.*, 2022). It is estimated that utilising around 11% of degraded land and desertification areas could meet the whole country's electricity needs in 2025 (Wang *et al.*, 2024).

In India, solar PV projects have demonstrated their suitability for deployment in arid and semi-arid regions, enabling maximum synergy for the potential control of desertification and degraded land (Rahman *et al.*, 2023). In California, United States, a solar PV plant deployed in the western Mojave Desert has also shown increased plant and animal species richness, and this effect was strongest in dry years (Tanner *et al.*, 2020). However, the impacts of solar PV plants on the desertification process may not be the same in every region or country. Careful assessment and siting selection are necessary to ensure the co-benefits and avoid unwanted impacts on desert ecosystems.

### Floating solar PV

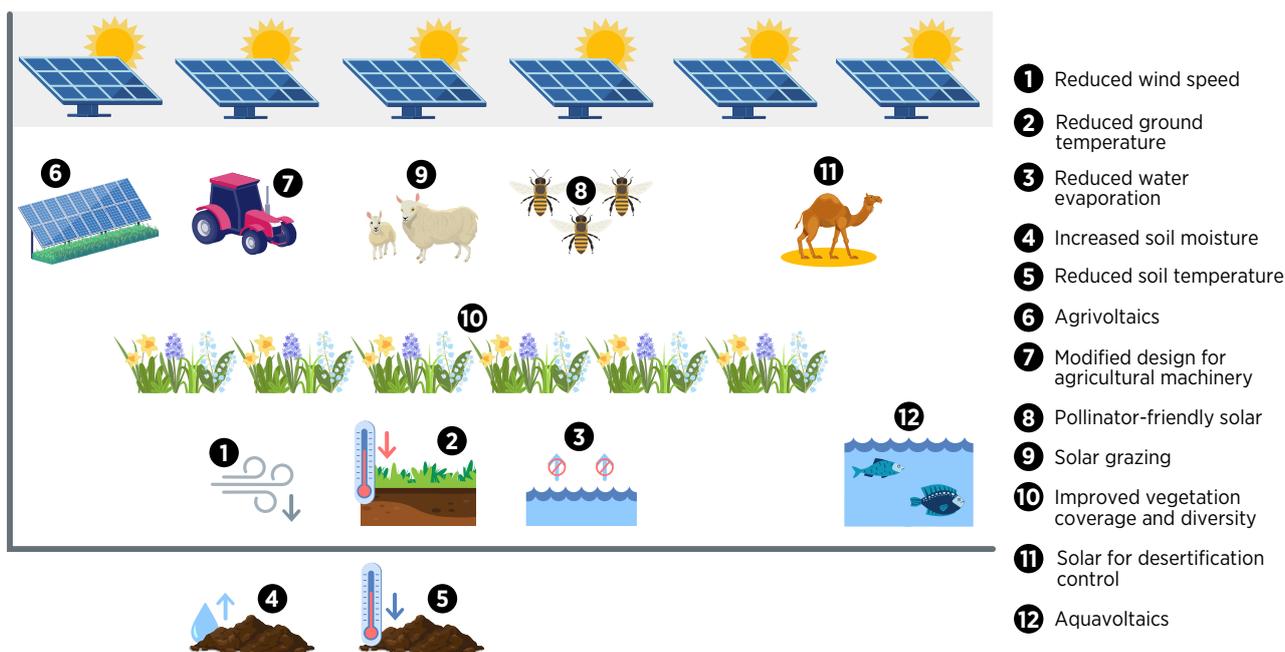
Floating solar PV projects involve installing solar PV plants on water surfaces and may combine them with aquaculture activities. They can impact the water ecosystem, potentially reducing both water evaporation and detrimental algal growth, while also enhancing water conservation efforts, especially in drought-stricken regions (Forester *et al.*, 2025). These projects may provide mutual benefits for both the host water body and solar power generation, reducing panel dusting, algal blooms and evaporation rates. They can also reduce shading loss compared to deployment in areas surrounded by high buildings.

Furthermore, by reducing exposure to strong solar radiation, floating solar PV projects may improve water quality and benefit aquatic species (Song *et al.*, 2024). In the Netherlands, a 27.4 MW solar PV project is deployed on a water surface in a sandpit near Zwolle. More than three years of monitoring showed an increase in the number and diversity of water species, including fish, vertebrates, mussels and sponges, below the floating solar panels (SolarPower Europe, 2022). In Dongying City (China), a 200 MW floating solar PV project is combined with aquacultural activities. It increased the production yield in shrimp farming by 50% (WRI China, 2025).

## 3.4 OTHER SOLUTIONS AND PRACTICES

Water management can be a key factor for solar PV projects combined with agricultural, desertification combating or ecological conservation activities (see Figure 20). This includes efficient irrigation technologies, water storage and rainwater management. Rainfall captured by solar panels may increase the risk of soil erosion if not managed properly. Collecting this rainfall and reusing it for plants in solar farms can be a win-win solution. Pilot projects in Jodhpur (India), Dongchuan (China) and Morogoro (United Republic of Tanzania) all revealed that including additional structures to collect rainwater from solar panel arrays can be a significant solution for water conservation and irrigation for agrivoltaics. This also reduces runoff risks associated with PV panels.

**Figure 20** Possible interactions and co-benefits of solar PV plants with soil, wind and temperature



The energy generated by PV systems could be used to power water pumps or water treatment systems (e.g. desalination in coastal areas). Solar irrigation, among the most mature applications, is being adopted to improve water supply and increase agricultural productivity. Currently, over 670 MW of solar PV power is used for irrigation pump programmes, with the majority located in Asia. In India, solar-pumped irrigation can increase farmers' income by 50% compared to rainfall-dependent irrigation. In Rwanda, solar-pumped irrigation can increase agricultural productivity by more than 30% (Energy4Impact, 2021; GOGLA, 2019; IRENA and FAO, 2021).

To promote sustainable practices, localised solutions are necessary. All the impacts of these solutions are relevant to the local environment, including the climate, geographic conditions and socio-economic status. The most suitable place for each solution should be based on local conditions.

In the case of agrivoltaics, suitability is also relevant to local markets where farmers can sell agricultural products, or where environmental experts can be involved in project planning. In the case of solar power plants for combating desertification and recovering degraded land, the effectiveness of the measure may depend heavily on climate and precipitation. Experience has shown that, while replantation and natural vegetation recovery may be sufficient for areas with over 400 millimetres of precipitation, other drier areas with less than 200 millimetres of annual precipitation require more efficient irrigation technology, replantation of native plants and measures preventing quicksand activity (Shang *et al.*, 2025). Localised solutions also indicate the necessity of using native plants, which save on maintenance costs, reduce the need for herbicides and mitigate soil erosion issues. In the United States, native vegetation deployed in solar PV plants has resulted in higher biodiversity and abundance (TNC, 2023).

Environmental and biodiversity-related stakeholders and the local community should be actively involved throughout the entire process of solar PV projects. Environmental organisations and institutes can be engaged in the planning process and impact assessment before construction, as well as in soil, water and biodiversity monitoring during the operating period. In Spain, a floating 138 MW capacity solar project deployed at Sierra Brava reservoir has involved conservation organisations and experts, to support monitoring and conservation measures to mitigate the project's impacts on birdlife and the ecosystem. This continuous collaboration has also enhanced the confidence of and engagement with local communities and municipalities.

International conservation organisations actively promote solutions and best practices through cross-sector platforms to support environmentally friendly planning and operations for solar PV companies. IUCN initiated the Renewables for Nature (REN) Coalition in 2021, bringing together energy stakeholders and conservation organisations to provide guidelines, tools and best practices for developers and policy makers to mitigate biodiversity impacts associated with solar and wind projects. In the same year, CLEANaction was launched by World Wide Fund for Nature, IRENA, BirdLife International and other stakeholders to minimise the environmental impacts of the energy transition through knowledge exchange, the promotion of guidelines and policy advocacy. More similar regional and national platforms are being developed to play active roles in promoting existing solutions and support the expansion of sustainable practices.

### 3.5 FROM ENVIRONMENT TO THE COMMUNITY

Solar PV plants' environmental impacts directly affect both biodiversity and local communities. Solar PV plants deployed in remote areas can provide reliable renewable electricity to nearby communities, improving their quality of life and resilience while adding economic value to the crops they produce. These plants can also provide local workers with jobs needed for agrivoltaics or solar grazing, creating new markets for local contractors (e.g. replantation or vegetation management) and diversifying landowners' income from energy generation and agricultural production.

Solar PV integration with environmental considerations provides seasonal jobs to the local community. In Gonghe County, China, people from local villages work at solar PV plants cleaning panels, managing vegetation and performing other tasks. In SPIC's 70 MW power plants in Inner Mongolia (China), planting native species under the solar panels (covering around 160 ha) requires around 20 local people to work for two months. Cutting dry grass in autumn to avoid fire hazards requires an additional month of a similar group of labourers (SPIC, 2025). Combining solar PV plants with environmental considerations may also bring indirect benefits to local communities. For example, in the United States, the deployment of solar PV plants on brownfield sites was found to increase nearby home property values by 5-15% within a 1.6 km radius around the PV plants (TNC, 2023).

Farmers can benefit from being involved in the operation of solar PV plants that integrate environmentally friendly practices, such as sheep grazing. In Canada, a study found that utility-scale solar farms combined with sheep herding can increase farmers' economic profitability to 10% to 40%, depending on how the sheep are sold in markets. This is higher than the agricultural average (7.3%). This takes into account all investments, including breeding, equipment, vehicles and labour costs (Gasch *et al.*, 2025).

Early stage, transparent and meaningful local consultation processes must be established for local communities affected by renewable energy projects, with measures in place to allow them to withhold consent if the costs are too high and the benefits are too low. Proper and transparent public participation helps speed up planning processes by ensuring that potential environmental concerns, including related legal issues, are addressed early (IRENA Coalition for Action, 2024). Furthermore, involving local communities can be highly beneficial for raising awareness of the local benefits of renewable energy and for identifying and mitigating potential risks and misperceptions (EEB, 2022).

## CHAPTER 4

# BARRIERS TO ADOPTING ENVIRONMENTALLY FRIENDLY PRACTICES AND HARNESSING CO-BENEFITS

An environmentally friendly and sustainable solar PV project requires proper assessment of potential negative impacts on the environment and biodiversity, and the adoption of necessary measures to avoid, minimise and mitigate these impacts. It also includes practices to utilise the interactions between solar PV project operations and the local environment and create co-benefits for biodiversity. Globally, it is estimated that a negligible share of existing solar PV plants have integrated proper considerations and solutions related to their interactions with the local environment, either preventing or mitigating impacts on the local environment and biodiversity, or harvesting the co-benefits by combining solar PV plants with agricultural-, economic- or conservation-related activities. Most of these sustainable practices remain at the pilot stage. They have been reported in markets including China, Europe, India, Japan, Kenya, the United Republic of Tanzania and the United States.

In most developing markets, the impact and benefits of solar PV projects exist mainly as topics of discussion in academic contexts or on a limited experimental scale, often linked to universities and institutes with involvement from European experts. The slow expansion of these sustainable practices beyond a few major solar PV markets can be attributed to various barriers. These barriers include high upfront costs, knowledge gaps, unclear or inconsistent land-use policies, challenges related to smallholder farmers' tenure rights, as well as a lack of industrial standards (see Figure 21).

**Figure 21** Key barriers to the adoption of environmentally friendly solar PV operation

ADDITIONAL COSTS	KNOWLEDGE AND AWARENESS GAPS	UNCLEAR OR INCONSISTENT LAND-USE POLICIES	CHALLENGES RELATED TO SMALLHOLDER FARMERS	LACK OF INDUSTRIAL STANDARDS
<p>Higher costs for adaptive PV construction and design</p> <p>Additional costs for maintenance arising from changed environmental factors</p> <p>Additional costs for equipment and professional work needed for the monitoring and assessment of environmental impacts</p>	<p>Unclear long-term impacts on ecosystem, such as the impacts on the water, desert or seabed ecosystem</p> <p>Unclear energy performance and economic returns of adaptive project design</p> <p>Unawareness of stakeholders in developing and emerging markets about existing solutions and practices</p>	<p>Land-use policies may not be clear enough to guide the renewables industry on potential land areas for agrivoltaics</p> <p>Unclear classification of land-use change status for agrivoltaics</p>	<p>Smallholder farmers may lose tenure rights</p> <p>Increased land leasing price for smallholder farmers</p>	<p>Lack of standards for adaptive construction process and materials tailored for local conditions</p> <p>Lack of standards for integrating existing environmental avoidance and minimisation tools into project development process</p> <p>Lack of standardised practices to ensure economic viability</p>

## High cost for adjusted equipment and eco-friendly practices

Solar PV plants, combined with environmental considerations, usually require additional investments to adjust commonly used mounting systems or practices to avoid and minimise environmental disruptions.

Agricultural activities combined with solar PV are the most feasible and attractive eco-friendly practices for many markets. However, costs can increase due to the elevated structures required by mechanised farming between rows. While there is no standardised clearing requirement for agrivoltaics across regions, solar PV designs with low clearing and narrow spacing may not be suitable for tractors and other agricultural equipment. Elevated panels can accommodate the machinery but can also increase installation costs. In most areas of the United States, elevated panel heights above 2.4 m may not be economically viable (Stewart *et al.*, 2025). However, the estimated cost differences for between-row agrivoltaics are less significant compared to elevated agrivoltaics.

In Europe, agrivoltaic systems can be 1.3 to 2 times more expensive than conventional ground-mounted solar power plants on a per kW basis (Rahman *et al.*, 2023). Most of these higher costs are due to additional investments in an adapted structure and higher installation costs. In the United States, elevated solar plants for agricultural applications have higher installation costs, ranging from USD 0.07 to USD 0.80 per watt of generated electricity, which is between 4% and 52% higher than for conventional ground-mounted PV installations of equal energy output. In Chile, a pilot project producing blueberries beneath solar panels may incur 22% higher installation costs compared to other solar installations (Chirinda *et al.*, 2024). In Japan, farmers also reported a 50% increase in racking costs for an agrivoltaic project.

Deploying solar PV plants on degraded land, while considering environmental factors, can also pose high-cost challenges. Construction costs for deploying solar PV on abandoned mining sites and brownfields may increase due to local conditions, which may require additional foundation work or additional land treatment to ensure safety and avoid contamination. In the United States, the construction cost of solar farms built on abandoned mining sites can be 10-15% higher than those built on common greenfield sites (TNC, 2024). However, these cost differences can vary widely depending on factors such as the system's size or capacity, land conditions, and PV module type and positioning.

Several large-scale (hundreds of MW or larger than GW) solar PV plants have been deployed to combat desertification in northwestern China, including Inner Mongolia and the provinces of Qinghai and Gansu. Additional environmental assessment and protection measures – including environmental and biodiversity baseline assessment, onsite environmental monitoring appliances, vegetation recovery, efficient water irrigation systems, adjusted construction and cabling processes, as well as other relevant measures – will incur additional costs estimated at several hundred thousand USD to over a million USD. However, considering the scale effect, these additional costs are estimated to be less than 1% of the initial investments in these large-scale solar PV plants (SPIC, 2025). These cost concerns can be further reduced by taking into consideration the additional benefits linked with reduced GHG emissions and avoided negative environmental externalities.

Additional costs may also occur during a project's operation and maintenance. This may include a rainfall collection and storage system attached to the agrivoltaic plants, providing water for irrigation. Other additional costs could include rainfall collection pipes, additional support for panel structures, water storage facilities and irrigation pumps. Additional work may also be needed annually to prevent the mounting's structural decay caused by a higher-humidity micro-environment between vegetation and solar panels. In India, for example, an agrivoltaic project installed in 2017 in the arid areas of Rajasthan found that the base portion of the structure corroded much faster than the rest due to higher moisture levels, incurring additional maintenance costs (Rahman *et al.*, 2023).

In the cases of solar grazing and agrivoltaics, additional investments in environmentally friendly measures could yield economic returns within a few years. In India, an analysis of an agrivoltaic project in Chennai found that an agrivoltaic project had a six-year payback period, compared to seven years for traditional solar PV

projects that did not integrate agriculture (Anusuya *et al.*, 2024). These projects have higher profitability than conventional ground-mounted PV systems due to dual revenue streams from energy and crops. The profitability can be enhanced by growing high-value crops, such as grapes, cherry tomatoes and coloured capsicums. However, these payback periods can be influenced by many factors, including agricultural yield; crop type; water-use efficiency; PV panel shading effects on microclimates; and local costs for installation operation, and maintenance.

### **Knowledge gap about long-term impacts on nature**

Many projects in major solar PV markets have deployed pilot projects that harness the co-benefits of solar PV panel shading and changes in temperature, moisture, soil and water conditions, as well as enhanced vegetation growth and diversity. However, most of these observations have occurred in the last few years. As solar PV expands rapidly in many new areas, its impacts on biodiversity and ecosystem services will continue to evolve, and existing projects and studies may not fully capture the long-term impacts on biodiversity and wildlife habitats.

For example, solar PV installed on water bodies can affect the water body's temperature and may control harmful algae blooms. However, how such an installation may affect the entire water ecosystem in the long term remains unclear. Similarly, sheep grazing offers multiple benefits for farmers and PV plants, and has been employed in many markets. Despite this, the optimal sheep stocking densities for solar PV plants that balance the benefits to nature and energy remain unclear (Stewart *et al.*, 2025).

### **Unclear or inconsistent land-use policies**

Inconsistent sector regulations and policies remain a major concern. Legislation related to energy, agriculture, the environment and land-use policies is not always co-ordinated or aligned. This can increase risks and costs for renewable energy developers and discourage sustainable practices. Land-use policies are relevant across multiple sectors. The restrictiveness or integration of land-use policies can prevent or encourage solar PV companies to deploy projects on specific types of land.

In most countries, agricultural land-use policies have been a key measure to ensure food security; therefore, changing land use to other purposes can be challenging. In some contexts in the United States, for example, solar panels cannot be sited on agricultural land or are not permitted on high-quality soils suitable for agricultural production (Guarino and Swanson, 2023). When the land-use policy lacks a clear definition of the conditions under which solar PV projects can be combined with agricultural activities and the criteria that must be met in these projects, solar developers may hesitate to promote such practices due to fear of fines or legal action.

In India, land-use and tax laws currently distinguish between agricultural and non-agricultural activities with associated restrictions on their use and tax benefits. Since agrivoltaics have emerged in several states, existing laws may not be as clear as needed for solar PV projects integrating with agricultural activities (Rahman *et al.*, 2023). Another example includes policies relevant to floating PV projects. Since the long-term impacts of floating solar PV are unclear and can vary across contexts, national land-use policies may struggle to keep pace with local conditions. In this case, inconsistent land-use policies could discourage the development of solar PV plants on water bodies, including on ponds on abandoned mining sites, which offer clear environmental benefits.

### **Challenges related to smallholder farmers**

Smallholder farmers may face challenges related to rising leasing costs or difficulty in securing tenure rights. When solar PV developers plan large-scale agrivoltaic projects, the targeted land may also hold importance for smallholder farmers. These smallholder farmers may be marginalised because landowners may prefer more attractive leasing offers from solar PV companies. For example, energy production usually yields higher returns compared to agricultural activities. In Germany, the leasing price for solar farms (over EUR [euro] 3 400/ha, equivalent to USD 3 942/ha) can be ten times higher than that for

normal agricultural activities (around EUR 300 - EUR 400/ha, equivalent to USD 348 - USD 464/ha) (ENLAPA, 2025). In Maryland, United States, solar companies' lease rate offers can be two to six times (and even more) higher than those for crop production (Sorensen *et al.*, 2022). In the meantime, smallholder farmers may be constrained by a lack of technical capacity and skills to implement and maintain emerging practices (e.g. solar PV integration with agriculture, solar grazing) and may find it challenging to access the required training. A just and inclusive framework to protect the interests of smallholders should be a key consideration for policy makers.

### Lack of industrial standards and guidelines

Currently no standardised definition or practice guidelines for agrivoltaics or solar grazing exists. In different regions, demonstration projects may be closely linked to local contexts and differ from one another.

Even though many solar PV plants in China, Europe and the United States have taken measures to recover vegetation, protect wildlife habitats, and combine these practices with agricultural activities to receive economic benefits, there is still no standardised practice (e.g. standards for material use, project design and construction) for solar PV companies and farmers in most developing and emerging markets. The construction and maintenance of solar PV plants have a significant influence on whether interactions with biodiversity and the broader environment are large or can be minimised. However, most of these experiences remain in the hands of large solar PV investors who place rigorous environmental considerations at the strategic level. These large companies are usually able to afford the resources and capacity to promote pilot projects that assess environmental impacts and take measures in a science- and data-based manner. Outside of these leading solar investors, small solar PV companies and developing markets may struggle to identify the key components of sustainable practices for building solar PV projects that are harmonised with the environment and nature.

In the cases of agrivoltaics and solar grazing, as well as solar for combating desertification, experience and knowledge suitable for the local context come mainly from the operation of pilot projects. Farmers and sheep owners may not be aware of which crops, fruits or vegetables are best suited to agrivoltaics in their local context. Solar PV companies may also take time to explore the best height, shading area and spacing between panel arrays that allow for mechanical operation. Yields of agricultural activities and sheep grazing depend on factors such as plant choices, agroclimatic conditions and panel density (Rahman *et al.*, 2023). Balanced water irrigation and the use of native plants in solar projects deployed on degraded land and areas affected by desertification vary widely across most solar PV companies.

Furthermore, there is a lack of standards on which environmental aspects and indicators should be monitored and addressed. As a result, assessment by solar PV companies or independent institutes may not be accepted by conservation organisations and NGOs. The lack of standards can also affect confidence in the assessment of long-term environmental impacts.



## CHAPTER 5

# POLICY FRAMEWORK FOR PROMOTING SUSTAINABLE SYNERGIES BETWEEN SOLAR PV PROJECTS AND THE LOCAL ENVIRONMENT

## 5.1 OVERALL POLICY FRAMEWORK FOR SUSTAINABLE SOLAR PV PROJECTS

Global sustainable development organisations have called for synergies between solar PV deployment and environmental protection. Three major international conventions, including the United Nations Framework Convention on Climate Change (UNFCCC), the Convention on Biological Diversity (CBD) and the United Nations Convention to Combat Desertification (UNCCD), have called for sustainable development with commitments to land, biodiversity and climate change. These international efforts have increased the urgency with which countries and regions are advised to balance energy, biodiversity and land issues. Renewable energy, including solar PV plants, remains one of the most promising solutions to address current threats and further promote sustainable development goals. Achieving such commitments and realising co-benefits through renewables requires integrated policy frameworks and appropriate incentive structures (see Figure 22).

**Figure 22** Policy framework for maximising synergies between solar PV and the local environment

<b>REGIONAL, NATIONAL AND SUBNATIONAL LEVEL POLICIES</b>	Long-term targets and plans balancing solar PV deployment and environmental considerations		Consistent and clear land-use policies tailored for local contexts	<b>ENVIRONMENTAL IMPACTS MITIGATION HIERARCHY:</b> <ul style="list-style-type: none"> <li>• Avoidance</li> <li>• Minimisation</li> <li>• Mitigation</li> <li>• Offset</li> </ul>
	Cross-sector collaboration and harnessed regulations for sustainable siting and permitting processes		Integrated policies and regulations for sustainable construction, operation and end-of-life management of solar PV projects	
	Financial and fiscal incentives for sustainable practices and pilot projects		Policy tools, including strategic environmental assessments, cumulative impact assessments, etc.	
<b>INDUSTRIAL SOLUTIONS AND GUIDELINES</b>	Industrial standards and guidelines	Business models and best practices	Capacity building and trainings	<b>INTERNATIONAL COLLABORATION:</b> <ul style="list-style-type: none"> <li>• Data and information</li> <li>• Standards and best practices</li> <li>• Finance and investments</li> <li>• Policy advocacy</li> </ul>
<b>PROJECT LEVEL MEASURES AND TOOLS</b>	<ul style="list-style-type: none"> <li>• Environmental impact assessment</li> <li>• Strategic environmental assessment</li> <li>• Spatial planning tools</li> <li>• Biodiversity sensitivity mapping</li> </ul>		<ul style="list-style-type: none"> <li>• Cross-sector working groups for continuous monitoring and adapting</li> <li>• Local stakeholders engagement</li> </ul>	

Some approaches and principles can help policy makers and industrial players to identify the opportunities and drivers most suitable for their local context. For example, approaches identified by IUCN outline steps and phases to avoid and minimise potential impacts during planning and design, and to mitigate remaining threats through adaptive measures. In the meantime, continuous stakeholder engagement and protection of smallholders' interests should be key components of relevant policies and measures to maximise the socio-economic benefits to both nature and the local community.

Government strategies are an enabler for sustainable planning of individual projects. A national-level long-term strategy based on co-ordinated energy and environmental targets could send a clear signal to investors and avoid inconsistent policies from different divisions. Such a strategy should be supported by industrial standards and guidelines that can help expand sustainable practices from pilot projects into more markets. Policies should prevent the deployment of solar PV projects in areas that are legally protected or designated as high value for biodiversity. The deployment of projects can be encouraged on disturbed or degraded land, including brown lands and abandoned mining sites. In some contexts, utility-scale solar plants can be an option to combat desertification and the occurrence of sandstorms, maximising the co-benefits of land recovery and solar generation, as multiple projects in China, India and the United States have demonstrated. In addition, training and capacity building are needed to bridge the knowledge gap.

## 5.2 POLICIES AND MEASURES TO ADDRESS BARRIERS

Policies and measures are needed to address existing barriers and further enable the expansion of sustainable practices that can minimise negative impacts and promote co-benefits between renewables generation and environmental conservation. These policies include integrated long-term planning and targets, financial and fiscal incentives, industrial guidelines and standards, and dedicated capacity-building and training programmes (see Figure 23). At the same time, stakeholders from different sectors must be engaged to ensure these policies are integrated, inclusive and effective. These stakeholders include not only environmental and energy departments from national and subnational governments, but also environmental NGOs, research institutes, local communities and investors. Policies and measures also need to be adaptive, engaging these stakeholders from the early planning stage of solar PV projects and throughout the operation and decommissioning processes.

**Figure 23** Policies and stakeholders to address major barriers to the adoption of sustainable practices

BARRIERS TO THE ADOPTION OF SUSTAINABLE PRACTICES	POLICIES AND MEASURES	KEY STAKEHOLDERS
<ul style="list-style-type: none"> <li>• Additional upfront costs for modified equipment and sustainable construction/operation</li> <li>• Stakeholders unaware of existing solutions</li> <li>• Unclear or inconsistent land-use policies</li> <li>• Lack of technological skills or practical knowledge</li> <li>• Unclear long-term impacts</li> </ul>	<ul style="list-style-type: none"> <li>• Strategic environmental assessment approach</li> <li>• Long-term national energy targets integrating biodiversity considerations</li> <li>• Consistent land-use policies</li> <li>• Financial and fiscal incentives for innovative business models</li> <li>• Industrial standards and guidelines</li> <li>• Training and capacity building</li> </ul>	<ul style="list-style-type: none"> <li>• Energy departments</li> <li>• Environmental and ecological departments</li> <li>• Space planning departments</li> <li>• Grid companies</li> <li>• Renewables project developers</li> <li>• Local authorities</li> <li>• Investors</li> <li>• Local communities</li> <li>• Universities and institutes</li> <li>• Environmental NGOs</li> <li>• Other stakeholders</li> </ul>

## Strategic environmental assessment (SEA) for solar PV

A SEA is an important tool for mitigating impacts on local environments and biodiversity. While the EIA has been adopted by many countries as a mandatory process for the approval of individual projects, it has some limitations that must be complemented at the policy level through the adoption of SEA. Policy makers at the national, regional and subnational level can use this tool to assess the environmental and biodiversity impacts at a strategic level, involving assessments of areas (much larger than specific projects) over multiple years. Based on the SEA, projects planned for locations with assessed areas of low impact could apply for streamlined, simplified permitting processes. This tool offers an option for reducing the time required for project permitting and saving costs for government departments.

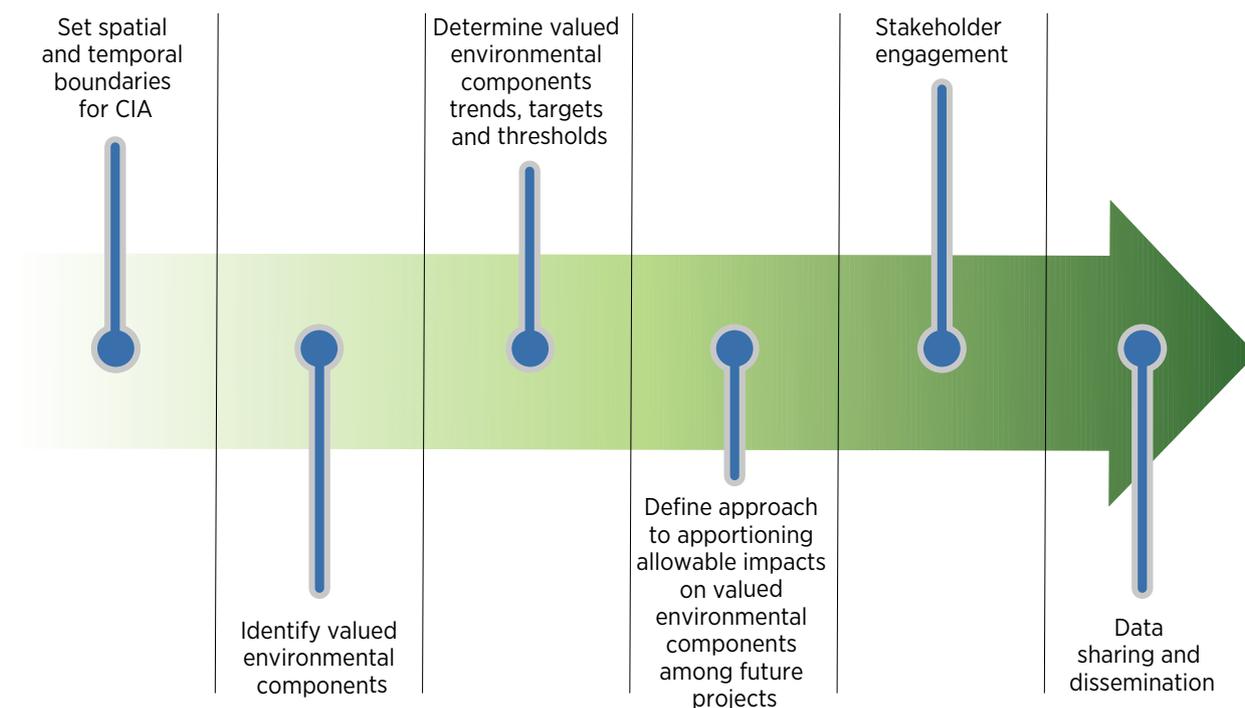
In Australia, SEAs have been applied to identify large areas for the development of energy activities. Once the environmental department approves the SEA for a large area, specific projects within the identified deployment acceleration areas do not require additional environmental permitting. In South Africa, SEAs have also been employed by related national departments since 2015. Through the SEA process, areas with higher levels of energy radiation and where environmental impacts can be identified are prioritised for the deployment of new solar PV projects. In the European Union, the Renewable Energy Directive has identified certain areas as renewable acceleration areas or artificial areas, which can contribute to a simplified permitting process for renewable projects.

A cumulative impact assessment (CIA) is another important tool that can support the government at the strategic level in environmental assessment. The impacts of project-level development can combine with other developments or human activities. When these environmental impacts accumulate gradually, they can be challenging to assess, and identifying a solution can be difficult.

A CIA can further strengthen the effectiveness of integrating renewables and environmental impacts through an assessment of the environmental impacts of past, existing and future projects that will affect the same ecosystem (see Figure 24). Based on a CIA, policy makers can ensure that an overall assessment of the environmental impacts of projects developed and planned by different developers/industries, as well as past and future projects and their impacts, is co-ordinated and does not exceed the environment's current and future capacity. A CIA of biodiversity enables policy makers to set spatial and temporal scales, identify valued environmental components and trends, and determine conservation targets and impact thresholds. Such an assessment therefore defines an approach to apportioning allowable impacts on environmental values (Bennun *et al.*, 2024).



**Figure 24** Key steps of a CIA in solar PV project planning



Based on: (Bennun *et al.*, 2024).

### Long-term national targets combining solar and environmental considerations

While many countries have announced long-term strategies, plans and targets for solar PV deployment, few of these are based on a combination of clear, quantitative ambitions for environmental and biodiversity outcomes. This may be relevant to the fact that, in most countries, energy targets and planning are defined by energy ministries, which may not share the same understanding and priorities as environmental or ecological departments. Long-term targets based on solar PV's environmental considerations need to be co-ordinated across multiple levels of government (*e.g.* national, state/province and local) and bring together actors and stakeholders within the relevant sectors to address concerns and propose solutions (Chirinda *et al.*, 2024).

In 2025, three Chinese national ministries – those in charge of long-term planning, energy, and forestry and land management – jointly announced a national plan to control desertification and degraded land in arid areas through solar PV deployment from 2025 to 2030. The plan aims to deploy 253 GW of solar PV plants in degraded and desertification areas in northern China and to recover 0.67 million hectares (ha) of degraded land by 2030 (NFGA *et al.*, 2025). In Europe, 14 of the 27 European Union Member States have incorporated solar PV into their national agricultural strategic plans (SolarPower Europe, 2022). The adoption of these integrated strategies and targets could send strong signals to industrial players and investors, thereby mitigating concerns about policy inconsistency.

### Restricted land-use policies to avoid disruptions in biologically sensitive areas

Land-use policies have been an effective tool for influencing the development of energy and infrastructure projects, including solar PV plants. A restricted land-use policy for consideration of solar PV plants' environmental impacts should clearly restrict development in areas legally protected for environmental and cultural reasons, or in areas with high biodiversity that development activities should not disrupt.

In the European Union, land-use policies are more restrictive than in most of other regions, aiming to protect forests and croplands. In this case, prioritising PV siting in degraded lands could avoid 88% of potential land-use competition between solar PV plants and forests and cropland by 2050 (Ferrerias-Alonso *et al.*, 2024). In Spain, zoning for environmental sensitivity is mandatory for solar PV plants, as regulated by land-use policies.

National restriction policies could also link with recognised global and regional databases by conservation organisations, including the IUCN Red List of Threatened Species™ (IUCN Red List), the World Database of Protected Areas (WDPA), the World Database of Key Biodiversity Areas (KBA) and several other resources. These databases indicate biogeographic regions, ecosystem/habitat type and extent, location of key habitat features, modelled indicative habitat suitability, species range maps, and verified point records of species occurrence (Bennun *et al.*, 2021a). In this way, land-use policies can be regularly updated, providing clear guidance for developers and stakeholders.

### **Financial and fiscal incentives for innovative business models**

Even though agrivoltaics and solar grazing have created financial returns for solar PV investors, most other sustainable practices entail additional costs with few near-term economic returns. For example, additional costs are incurred for desertification recovery in solar PV plants, for building wildlife corridors, and for changing low-impact techniques for cabling and mounting structure construction. Without national mandatory requirements, these measures represent an additional expenditure for solar companies' environmental and social responsibility efforts. Since the environment and biodiversity are usually defined as matters of public interest, governments have the responsibility to incentivise the adoption of environmentally friendly practices at the early development stage. They can mandate environmental requirements for the permitting and planning processes, as well as provide incentives for developers who prioritise appropriate measures to reduce unwanted environmental impacts and maximise co-benefits. These incentives can include tax incentives and subsidies, risk and credit guarantees, fair energy pricing, feed-in tariffs, and others.

Policies should also incentivise and encourage innovative business models that can translate solar PV plants' environmental benefits into profitable, sustainable businesses in the medium term to the long term. For example, in China, state-owned solar PV investors consider investments in revegetation and irrigation systems for combating desertification in northern China as part of their social responsibility. Project operators have begun exploring opportunities by harvesting native vegetation as a medicinal herb (cistanche) (SPIC, 2025). Even though such an innovative business model has not yet become commercially feasible, it remains a promising direction for scaling up sustainable practices, thereby enabling environmental impacts to lead to higher market-value products.

### **Industrial standards and guidelines**

Industrial standards and guidelines are urgently needed to address the knowledge gap and help scale up sustainable practices. These standards and guidelines could provide overall or specific guidance to industrial players on key considerations, steps, and available tools to promote environmentally friendly and sustainable practices. They should cover the entire process of solar PV plants, from planning and preparation to construction, operation and maintenance, decommissioning, and treatment.

Quality standards and guidance to support the implementation of environmental measures for solar PV plants should provide clear definitions or relevant practices and possible impacts. They should address topics like procedures and conditions for site selection, technical requirements, impact assessments, health and safety concerns during installation and operation, as well as other key steps and requirements. Such standards and guidance are needed to provide a shared understanding among project developers, governments and financing institutions, and are essential for policy development and the effective administration of incentives. The Nature Conservancy (United States), for example, has released relevant guidelines aiming to encourage the siting of renewable projects on degraded land, such as mining sites, landfills and brownfields, to minimise environmental impacts.

Industrial guidelines such as these are beginning to emerge in a few markets. In the European Union, the industrial association Solar Power Europe has started to provide guidelines to enable more sustainable agrivoltaic practices. Germany has also announced a national policy to guide the height, shading and agricultural production in agrivoltaic projects. However, these standards may not be suitable for emerging markets, where the majority of the needed solar PV plants are expected to be deployed by 2050. Limited financial resources and local expertise can further impede the knowledge expansion in developing markets.

### **Training and capacity building**

Training and capacity building for solar PV industrial players and relevant sectoral stakeholders are necessary to address the knowledge gap. For example, the scientific design of an agrivoltaic system to ensure optimal sunlight distribution is a skill-intensive process, and properly designed corridors for wildlife require environmental knowledge. Similarly, crop management under shading conditions requires advanced skills among farmers, and practitioners who aim to utilise solar PV plants to address threats posed by desertification require an understanding of the desertification process, land degradation and water management.

Addressing these cross-sector knowledge and information gaps requires training and capacity building that draw on expertise and experience from both the energy and conservation communities. Skill-building activities like these require efforts from national and local authorities, with co-ordinated resources from energy and environmental departments. These efforts also benefit from the involvement of international platforms and organisations, which may have the necessary expertise.

### **Support from international finance stakeholders**

Multilateral development banks and development financial institutions can play a critical role in filling these gaps and supporting countries dedicated to promoting environmental and social safeguards for renewable energy projects. Additional guidelines at the international level, supported by practical experiences and best practices, are needed for the future.

International financial institutions also play a crucial role when government capacity is limited and environmental regulations are absent. They can support governments in establishing the necessary policy framework, including regulations and incentives, as well as stakeholder and local community engagement throughout the process. This support can enable a sustainable planning and siting process that considers environmental and biodiversity impacts, as well as the improved energy access and socio-economic benefits the projects bring to developing markets.



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