CLEANaction
Coalition Linking Energy And Nature for action

IRENA coalition FOR ACTION

NATURE-POSITIVE ENERGY PRINCIPLES

ENVIRONMENTAL SITING AND PERMITTING OF SOLAR, WIND AND GRID INFRASTRUCTURE

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About the Coalition for Action

The IRENA Coalition for Action brings together leading renewable energy players from around the world with the common goal of advancing the uptake of renewable energy. The Coalition facilitates global dialogues between public and private sectors to develop actions to increase the share of renewables in the global energy mix and accelerate the energy transition.

About this paper

This paper has been developed jointly by members of the Coalition's Working Group on Empowering People and Communities, and the Coalition Linking Energy and Nature for Action (CLEANaction). These groups bring together a diverse range of stakeholders united by the goal of accelerating the energy transition in a just and inclusive way with nature considerations at its heart. This paper proposes the guiding principles to develop solar and wind energy and associated infrastructure in line with ecosystem conservation and restoration.

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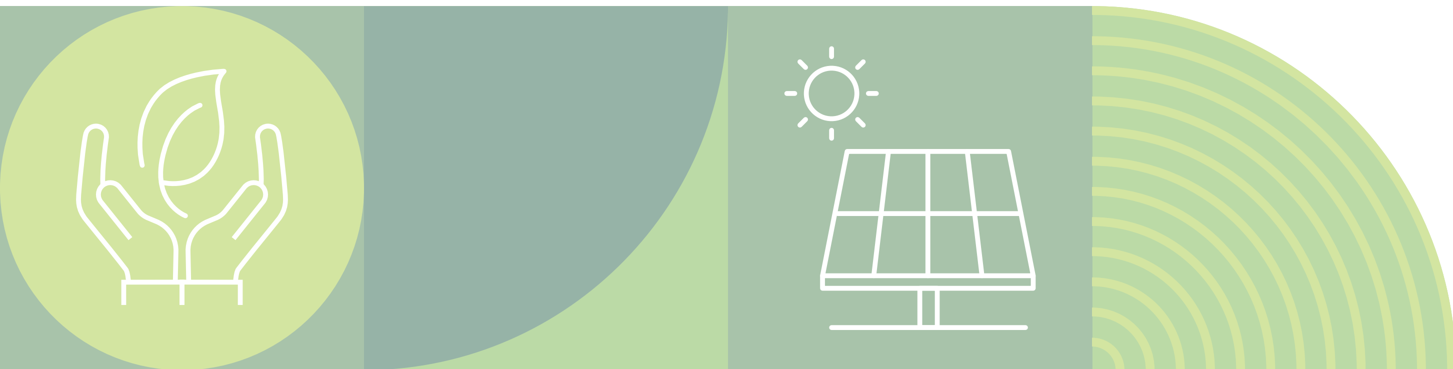
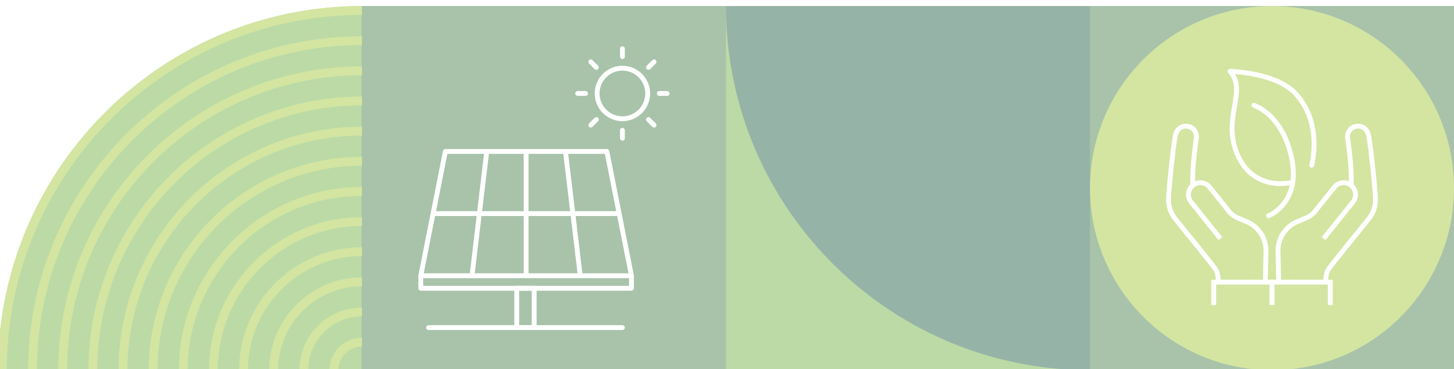


Abbreviations

AI	Artificial intelligence
BSC	biological soil crusts
CBD	Convention on Biological Diversity
COP28	28th Conference of the Parties
EIA	environmental impact assessment
EU	European Union
ESG	environmental and social governance
FPIC	free, prior informed consent
GAA	grid acceleration area
GBF	(Kunming-Montreal) Global Biodiversity Framework
GIS	geographic information system
GW	gigawatts
IRENA	International Renewable Energy Agency
KW	kilowatt
MW	megawatts
NGO	non-governmental organisation
PM-KUSUM	Pradhan Mantri Kisan Urja Suraksha evam Utthan Mahabhiyan Scheme
PV	photovoltaic
RAA	renewables acceleration area
SDG	Sustainable Development Goal
UAE	United Arab Emirates Consensus
UK	United Kingdom
UNCCD	United Nations Convention to Combat Desertification
UNDRIP	United Nations Declaration on the Rights of Indigenous Peoples
UNFCCC	United Nations Framework Convention on Climate Change
WWF	World Wide Fund for Nature



Executive summary

There are three main interlinked threats to human activities and the natural environment caused by the continuous use of fossil fuels. These threats are climate change, loss of biodiversity and pollution. Failure to address these threats means irreversible and unprecedented negative consequences for humans and nature alike worldwide (UNFCCC, 2022). The key action to address these threats is to replace fossil fuels with renewable energy sources across all sectors and activities.

By 2030, in line with the Paris Agreement and the 28th Conference of the Parties (COP28) UAE Consensus, the global installed renewable electricity capacity must triple. According to the International Renewable Energy Agency (IRENA), the 1.5°C pathway envisions decarbonisation of the energy sector driven by renewable energy, especially solar photovoltaic (PV) and wind, energy efficiency, and electrification that will require expanding supporting grid infrastructure (IRENA, 2024). In addition, by the end of this decade, the majority of countries have committed to halt and reverse nature loss under the Kunming-Montreal Global Biodiversity Framework (GBF) (CBD, 2024). Climate and nature commitments are deeply interrelated and must be addressed through integrated cross-sectoral planning that considers social, economic and environmental dimensions.

The current imperative for the energy transition from fossil fuels to renewables means great pressure to roll out renewables much more quickly than ever before. In this process, it is essential to ensure that the rapid energy transition effectively manages and limits any damaging impacts on biodiversity and ecosystems as well as on communities and local stakeholders. Extensive literature outlining good practices and guidelines already exists. Building on this, this brief proposes six guiding principles for accelerated solar PV, wind and electricity grid deployment in balance with nature as key drivers to decarbonisation as illustrated in Figure S1.

Figure S1 Six guiding principles for nature-positive energy development

Principle 1: Accelerate nature-positive energy development

To achieve the necessary increase in the rate of renewables roll-out and supporting grid infrastructure, governments should identify areas with a high resource potential for renewable power generation, together with minimal impact on nature, preserving conservation areas, biodiversity hotspots and cultural heritage sites.

Principle 2: Co-utilise

Priority should be given to the dual or multiple use of existing infrastructure and modified lands in combination with renewable energy projects. This includes leveraging existing structures and modified areas and establishing rules for dual use such as agriculture.

Principle 3: Conserve, restore, enhance

This principle requires active planning during the project development and implementation to conserve ecosystems as much as feasible, to restore impacts to the extent possible and to implement measures to enhance biodiversity in line with the mitigation hierarchy.

Principle 4: Monitor and adapt

Recognising complex and evolving nature interactions, this principle highlights the need for adaptive management monitoring the potential impacts of the project across the construction, operation and end-of-life phases and making adjustments in response to new evidence.

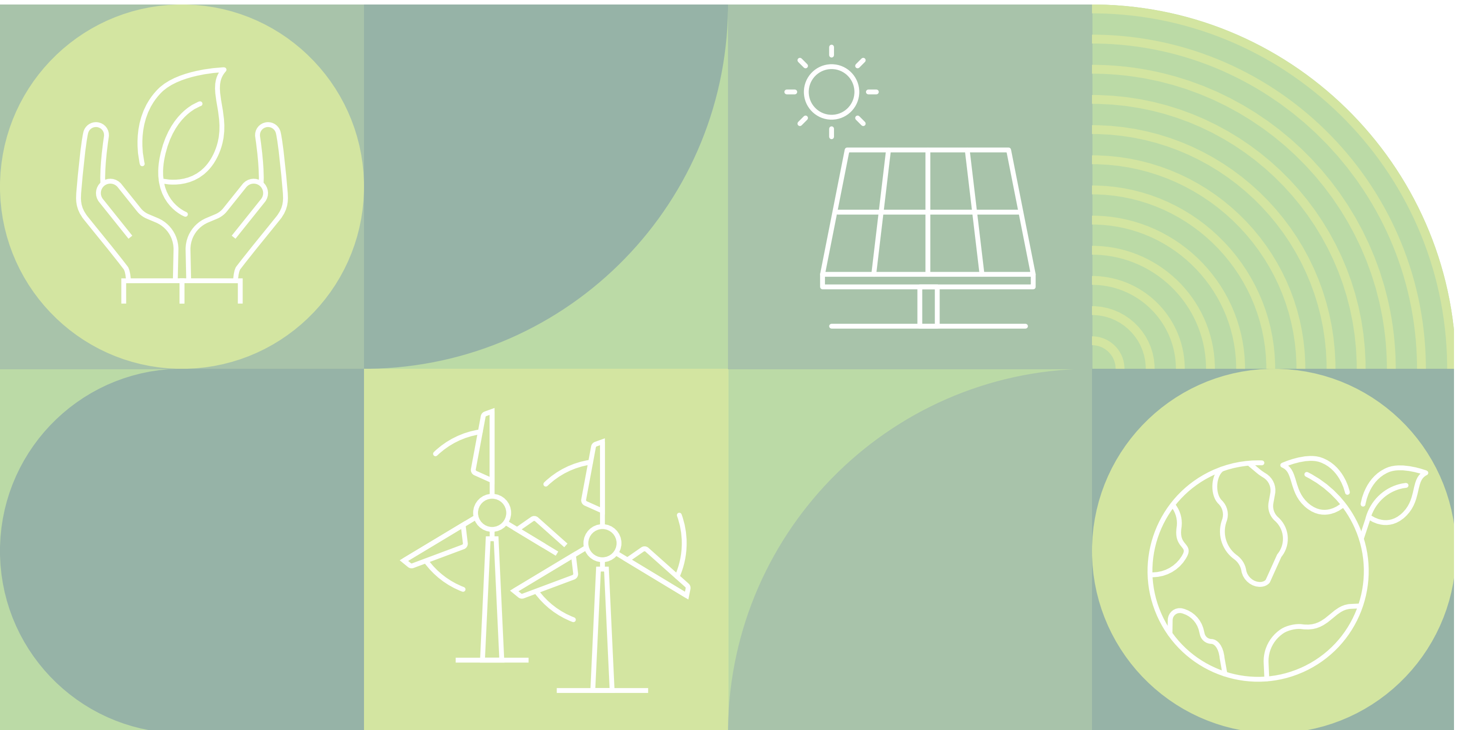
Principle 5: Extend the useful life

This principle focuses on extending the useful life of already operating renewable energy installations to minimise negative environmental impacts and maximise resource efficiency. It covers appropriate maintenance, refurbishment, repowering, decommissioning and circular economy applications.

Overarching Principle 6: Engage local actors

Across all aspects, it is important to engage communities and local stakeholders; adapt to the local context including history, culture, heritage and social values; incorporate local knowledge; ensure the equitable distribution of benefits; and create opportunities for meaningful participation in decision-making.

To create an enabling environment for these principles' application, the paper calls for a more integrated approach that aligns energy development plans and Nationally Determined Contributions with international targets on climate, biodiversity and sustainable land management. More research and practical tools are needed on the application of technological innovations combined with scientific and local knowledge to enable robust adaptive management to protect and enhance ecosystems. The renewables buildout must be done fast, but it must be carried out responsibly to prevent environmental damage and conflicts that could lead to delays or irreversible harm on global biodiversity – outcomes the world cannot afford.



01 Introduction

The UAE (United Arab Emirates) Consensus calls for increasing renewable energy deployment in numbers and speed, tripling existing capacity by 2030, while phasing out fossil fuels and doubling energy efficiency improvements (IRENA, 2024). The transition to renewable energy is now widely accepted as a key component to avoid further environmental degradation and ensure the sustainability of ecosystems in the future (IPCC, 2020).

Renewable energy has been gaining traction for the last two decades, with 2024 achieving a record annual growth rate of 15.1%, with 585 gigawatts (GW) of renewable power capacity added representing 92.5% of total capacity expansion (IRENA, 2025). Solar photovoltaic (PV) energy accounted for over 75% of new additions, followed by wind at around 20%. Wind and solar energy are likely to continue dominating new capacity additions due to cost-competitiveness and faster deployment time frames (IRENA, 2024). Figure 1 illustrates renewable capacity, per technology, indicating the major role of solar PV and wind energy in meeting tripling targets (IRENA *et al.*, 2024). For this reason, this paper focuses on solar PV, wind and associated electricity grid infrastructure development.

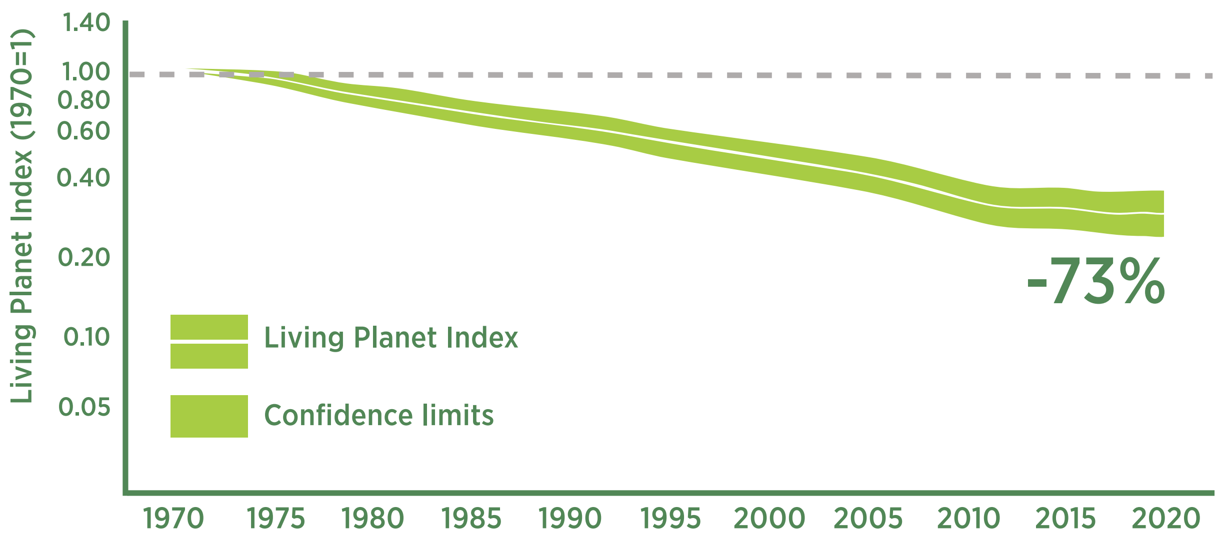
Figure 1 **Renewable capacity additions**

RENEWABLE CAPACITY ADDITIONS	2023	2024	Average annual additions 2024–2030
Annual additions (GW/yr):			
Renewable power capacity	473	585	1 044 GW/yr
Solar PV	346.9	452	578
Wind energy	114.5	113	360
Hydropower	6.6	15	29
Bioenergy	4.6	4.6	28
Geothermal	0.4	0.4	13
CSP	0.3	0.004	27
Marine energy	0.002	0.5	10

Note: CSP = concentrated solar power.
Sources: (IRENA, 2025) and (IRENA *et al.*, 2024)

The interactions between humans and nature are complex. While direct negative impacts on the environment caused by human activities are well known, the indirect and cumulative effects and feedback loops are still to be fully understood. According to the World Wide Fund for Nature (WWF), there has been a 73% biodiversity loss in the last 50 years. Figure 2 shows the trend of the Living Planet Index, which tracks the average change in global wildlife populations. Increasing population, and, especially, unsustainable consumption and production patterns continue to put pressure on limited land resources for competing demands: food, energy, water and shelter. Despite ongoing degradation, the natural environment holds intrinsic value as it sustains human life and all other living organisms. Furthermore, nature represents an effective tool for adaptation, helping to reduce and mitigate the negative impacts of climate change.

Figure 2 **Global Living Planet Index**



Tackling the interconnected crises of climate change, biodiversity loss, pollution and land degradation holistically will increase our chances of safeguarding nature while ensuring equitable and efficient use of resources. Under the Kunming-Montreal Global Biodiversity Framework (GBF), 196 countries recognised that biodiversity is fundamental to human well-being and committed to halt and reverse biodiversity loss by 2030. It is necessary to build stronger synergies among the three Rio Conventions on climate change United Nations Framework Convention on Climate Change (UNFCCC), Convention on Biological Diversity (CBD), and Convention on Combating Desertification (UNCCD) and the Sustainable Development Goals (SDGs).

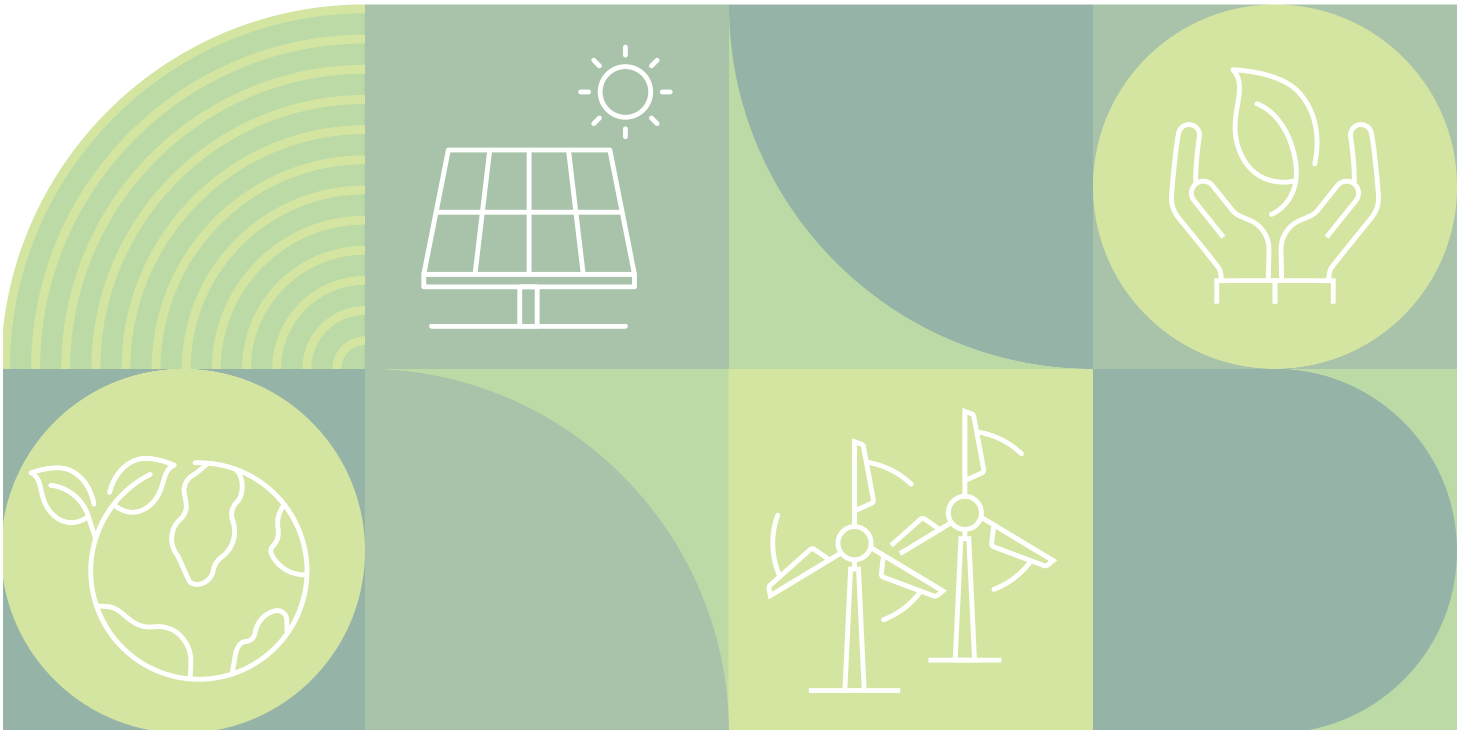
Nature-positive energy development is an approach that delivers net-positive biodiversity outcomes, aligning with the goal of halting and reversing nature loss by 2030 (Nature Positive Initiative, 2025). Protecting nature is paramount, and the continued use of fossil fuels poses one of the greatest threats to the environment, and consequently to the survival of the human population. Fossil fuels are responsible for three-quarters of global greenhouse gas emissions and 90% of carbon dioxide released to the atmosphere (UN, 2022). The environmental footprint of fossil fuels is associated not only with the land required for extraction, processing and transportation, but also with contamination of surrounding water resources and habitats. Additionally, production sites and the combustion of fossil fuels contribute to pollution, exacerbating environmental degradation.

Transitioning from fossil fuels to renewable energy, combined with energy efficiency measures, is the best chance to preserve the natural world. However, without careful planning, this global energy transformation could lead to avoidable negative socio-economic and environmental impacts contributing to ecosystem and land degradation throughout the value chain and the life cycle of the project (WRI, n.d.). Fortunately, there is sufficient previously modified land, where adverse impacts are likely lower than other places, that can be used to meet our clean energy needs – by some estimates at least 17 times the amount of land needed to meet the Paris Agreement goals (Nature Conservancy, 2021). Prioritising the use of these lands for renewables requires taking proactive measures now.

The buildout of renewables and associated infrastructure must be done fast, but it must also avoid nature-sensitive areas and maintain healthy ecosystems. Development and implementation processes must actively minimise negative impacts while enhancing positive impacts on people and nature throughout the life cycle of the technologies and projects (Tian *et al*., 2024). A study conducted in eight states in the United States found that currently barriers to renewable energy deployment have shifted from techno-economic to institutional and social at regional, state and local levels (Energy Environmental Economics, 2024). There is a need for policy, legislation and regulations to ensure that potential impacts on the environment and biodiversity are considered and assessed properly during the planning, permitting and siting of renewable energy projects. These legal frameworks must streamline and accelerate the deployment while avoiding compromising sensitive areas for biodiversity or undermining the well-being of communities affected.

The interaction with nature should not be considered a risk for renewable energy projects, but rather a potential asset. Working with nature and taking advantage of the range of benefits that biodiversity can bring to a renewable energy project can achieve novel social and economic opportunities. For example, clearing the natural vegetation from a site at the commencement of a project will not avoid the need for ongoing vegetation management, since vegetation usually finds its way back into a site. Instead of clearance, preserving vegetation ground cover can improve the resilience of the soil by maintaining soil structure, reducing the impact of erosion and dust, benefiting the microclimate, reducing ambient temperature, and outcompeting weeds. This could contribute to the preservation of local wildlife, their habitats and key corridors that support healthy ecosystems, providing essential services to local populations. Solar farms can enhance bird diversity, especially if designed with a focus on wildlife (Copping *et al*., 2025).

This paper focuses on siting and permitting processes to balance renewable energy and grid infrastructure expansion and environmental protection. It proposes principles to guide nature-positive renewable energy development. The principles encompass the consideration for long-term sustainability, inclusivity, and scientific and local knowledge integration.



02 Background, key definitions and stakeholders

This section provides key definitions and articulates issues and stakeholder interactions regarding siting and permitting of renewable energy and infrastructure projects. The section takes account of existing material available on this matter and prepares the ground for suggested pathways and best practices in the subsequent sections that could contribute to tackling these challenges.

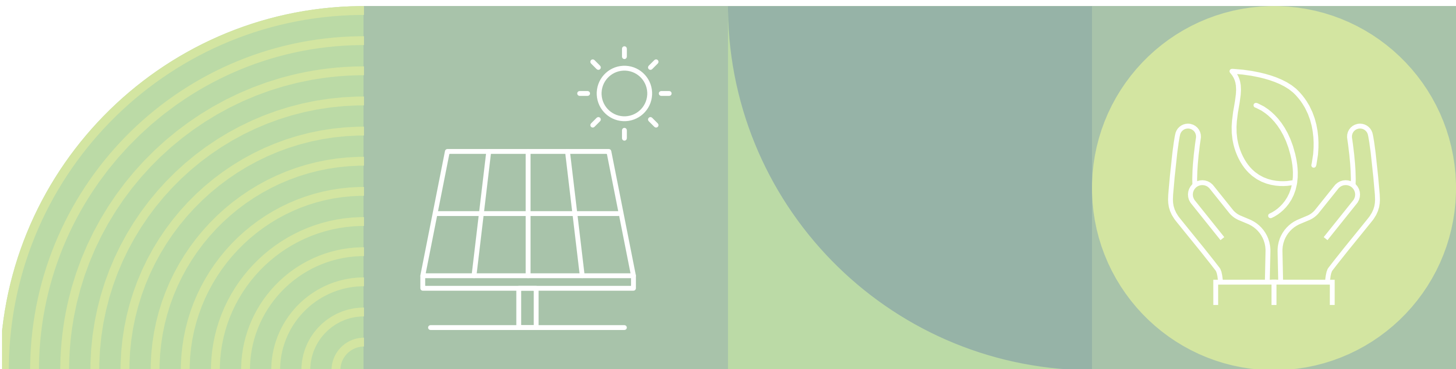
The abovementioned implementation challenge cannot be advanced and succeed without careful, but accelerated and impactful, land and marine use planning (hereinafter “land use”). Land use refers to the human modification of a specific space/area (land or maritime) for different purposes. Often, land use refers to the designated area for infrastructure or usage (“direct” land use). But one should also take into consideration “indirect” land use, i.e. other spaces/areas that are required to support the development of the infrastructure or use. Examples include the space required for extracting materials for technologies that are being used in other areas and the space between wind turbines (REN21, 2024) and electricity grid pylons.

Land use entails different aspects, with two that are particularly critical: siting and permitting. Siting refers to the process of allocating space (in land or in sea) for designating specific use. In renewable energy this means considering technical potential and allocating specific areas to establish energy generation facilities (*e.g.* wind energy) and transmission and distribution lines (the electricity grid). Permitting is the process in which public authorities provide the “green light” to developing a project in the area that was chosen during the siting process, under predetermined legal and regulatory requirements (Sercy and Cavert, 2024). During the permitting stage, environmental impact assessments take place, and communities are consulted on projects. This paper focuses mainly on siting and permitting in the context of direct land use, while acknowledging the contribution of indirect land use to some extent.

Siting and permitting of renewable energy projects and grid infrastructure involves interaction between multiple stakeholders. General project development stages that can be applied to many renewable energy projects are illustrated in Figure 3:

Table 1 **Stages of renewable energy project development**

Activity	Resource and technical potential assessment	Siting	Permitting	Site development and installation	Operation and maintenance	Repowering or decommissioning
Description	Assess technical potential of various regions and identify sites with highest potential of renewable energy resources.	Select locations with high technical potential and designate the site for renewable energy project and grid infrastructure. Economic and market potential estimate. Strategic environmental assessment. Selection of locations based on environmental sensitivity (*e.g*, bird/bat species) using siting tools (*e.g.* sensitivity maps that overlap with wind/solar/grid potential). Informal public and other stakeholder consultations.	Select developers, project design and planning, off-taker. Get environmental clearances, conduct public and other stakeholder consultations.	Construction and installation of renewable energy and supporting infrastructure.	Electricity generation, continued maintenance and support, adaptive management of environmental impacts, *e.g.* marking power lines to reduce collision risks for birds.	At the end of technical life of the project either decommission and site restoration to the agreed baseline, or repowering the site.
Decision makers	Governments, technical department, private sector.	National and sub national governments, private sector, local non governmental organisations (NGOs).	Governments, environment regulators, local communities, NGOs.	Investors, producers, developer, manufacturers and suppliers, government, regulator, electric utilities.	Developer, electric utility, electricity regulator.	Developer, recycler government.
Impacted stakeholders		Local actors (*e.g.* local businesses, fisheries, tourism sector, farmers, landowners and -users), communities, developers, manufacturers, local governments.	Local actors and communities, developers.	Local actors and communities.	Local actors and communities.	Local actors and communities.



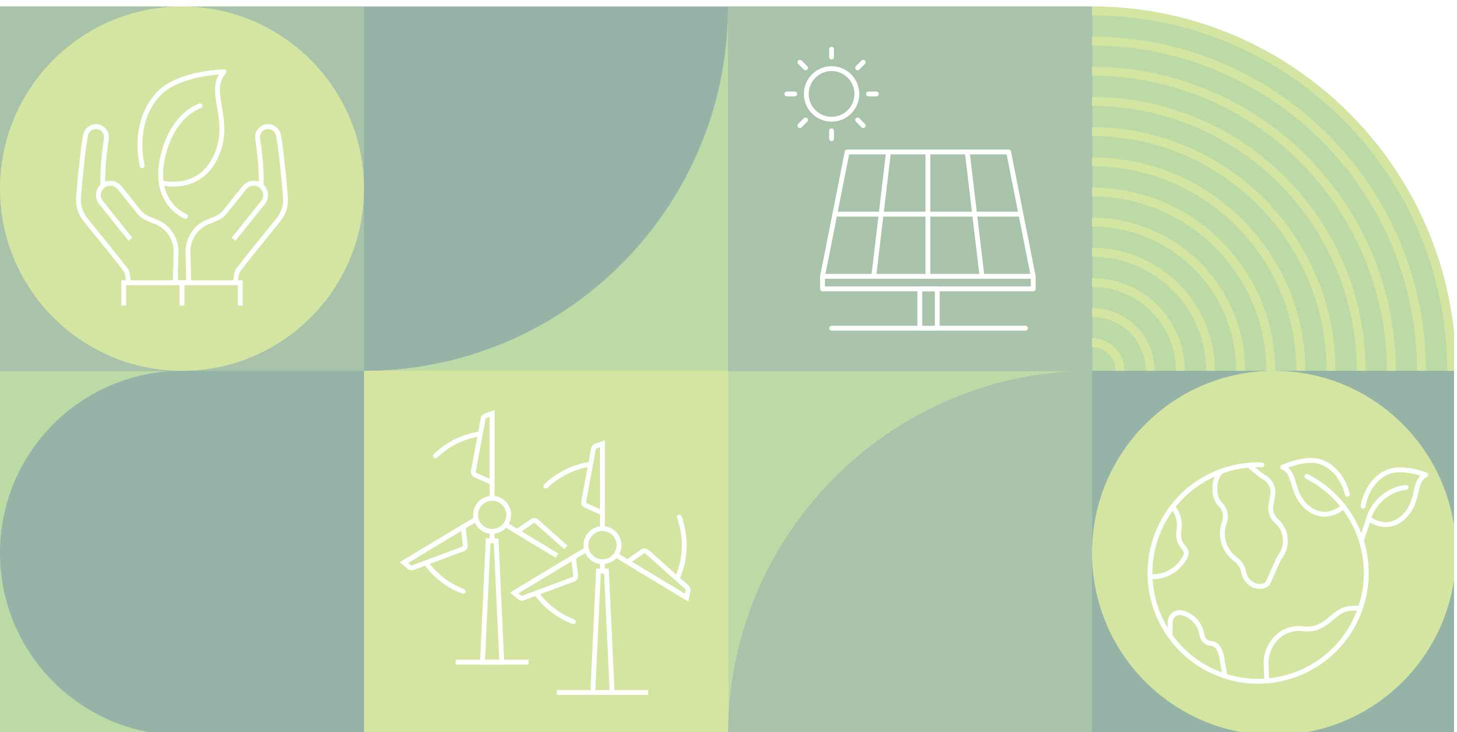
Both siting and permitting processes have inherent conflict: the need to prioritise, balance and integrate different stakeholder needs and activities with certain capacities and physical limitations of the natural environment of one specific geographical area. This tension is prominent in the context of renewable energy: new wind and solar farms, and new transmission and distribution lines necessary to support them, require designating and using new areas, or enhancing capacities of existing areas (multi-use/multiple use of land). The risks include, among others, clearing forests with adverse impacts on biodiversity and carbon storage, transforming fertile land that can be used for agriculture into solar and wind farms, impacts on marine environments by offshore wind farms, and establishing wind turbines or electricity grid lines without protections for migratory and other birds.

The contestation over land use in siting and permitting may be even more complex when considering the many different settings of where and how renewable energy can be deployed: for instance, using agricultural land for both agriculture and photovoltaic technology may require different siting and permitting processes as compared with using it for a solar or wind farm alone (IRENA Coalition for Action, 2025).

Siting and permitting processes need to account for a broad array of considerations in order to come up with the most feasible solution that will ease the conflict between the need for renewable energy and the impact it will create. The debate in the European Union (EU) on the planned Renewables Acceleration Areas (RAAs) and Grids Acceleration Areas (GAAs) is a good example of this inherent conflict on a large scale: the need to designate areas in EU countries for rapid siting and permitting processes for renewable energy while ensuring protection of natural areas and human activities (RGI, 2024). Despite this, studies have shown that there is enough low-conflict land in Europe to meet the European Union's regulatory renewable energy target of 45% by 2030, demonstrating the value of smart siting approaches to both the energy transition and nature protection goals (Kiesecker *et al.*, 2024).

Numerous stakeholders are involved in permitting and siting processes, with different motivations and power to act. Annex 1 provides a basic scheme of stakeholders. Effective interactions with other stakeholders are necessary for achieving their goals throughout this process.

Considering the diverse interests and the urgent need to dramatically reduce emissions through fast and vast deployment of renewable energy, improvement of siting and permitting processes is needed. Integrating social, environmental and biodiversity considerations in siting and permitting processes can minimise the potential adverse effects and enhance the positive impacts of renewable energy projects.



03 Guiding principles for nature-positive energy

Acknowledging the importance of environmentally and socially responsible renewable energy deployment, national and sub-national governments – supported by the international community and in consultation with the private sector and civil society - should put in place frameworks and allocate appropriate resources to support all stakeholders involved in these processes. The benefits can be manifold. Strategic thinking on siting and permitting can mitigate land-use conflicts that might otherwise hinder the deployment of renewable energy, identify synergies with other activities, and ensure that ecosystems and communities can thrive in the transition towards net-zero society. The guidance on siting and permitting can also strengthen the local environmental and socio-economic impact assessment of the project.

There is a need to develop and endorse internationally recognised guidelines for renewable energy siting and permitting in harmony with nature. This paper contributes to this effort by providing guiding principles for accelerated solar, wind and grid infrastructure development in balance with nature (Figure 3). Six principles are set out, recognising that their application will depend on local characteristics and the type and scale of the project:

1. **Principle 1: Accelerate nature-positive development** calls for an integrated approach to identifying and designating areas with high potential and minimal environmental impacts enabling more streamlined deployment.

1. **Principle 2: Co-utilise** emphasises that the priority should be given to already modified areas, as illustrated by numerous examples in cities, agriculture and infrastructure projects.

1. **Principle 3: Conserve, restore and enhance** applies to all projects, including when co-utilisation is not feasible (*e.g.* some cases of electricity grid, energy access, or large-scale and offshore wind projects) with measures to preserve existing biodiversity, restore modifications as much as possible and strive to enhance biodiversity in line with the mitigation hierarchy.

1. **Principle 4: Monitor and adapt** acknowledges that ecosystems are dynamic and complex. Adaptive management approaches and technologies should be used to adjust to emerging evidence of wildlife movement or plant growth.

1. **Principle 5: Extend the useful life** concerns already existing projects with measures to extend the planned project's life cycle to continue producing energy without the additional environmental impacts of new constructions.

2. **An overarching Principle 6: Engage local actors** is essential for all projects throughout all the development phases. Measures for community participation and engagement are required to achieve public support and utilise local traditional and scientific knowledge, which will contribute to the long-term success and sustainability of the project.

Each principle provides examples of policy tools and case studies illustrating successful applications. These principles align with existing guidelines and research, such as the IUCN "Spatial planning for wind and solar developments and associated infrastructure" (IUCN, 2024), the IUCN Mitigating Biodiversity Impacts Associated with Solar and Wind Energy Development: Guidelines for Project Developers (Bennun *et al*., 2021), IUCN Guidance on Biodiversity Cumulative Impact Assessment for Wind and Solar Developments and Associated Infrastructure (Bennun *et al*., 2024), the REN21 Renewable Energy and Sustainability Report (REN21, 2024), and "Principles for responsible deployment of renewable energy infrastructure" (WEF, 2025), among others.

Figure 3 **Six guiding principles for nature-positive energy development**

Principle 1: Accelerate nature-positive energy development

To achieve the necessary increase in the rate of renewables roll-out, governments should identify areas with a high potential for renewable power generation while avoiding nature-sensitive areas.

Decision makers must weigh the potential impacts on biodiversity and local communities when identifying appropriate sites for new renewable energy and transmission and distribution infrastructure. The expansion of renewable energy should be planned carefully in order to avoid and reduce potential negative impacts on nature and people. This requires a collaborative process designing renewable energy zones for responsible siting and permitting.

Smart siting tools and approaches can be used to identify renewable energy development locations that consider criteria such as energy resource potential, sensitive habitats, high-risk areas for vulnerable species (*e.g.* birds), priority cultural areas and more. By developing smart siting tools and approaches that consider unique local needs, renewable energy projects can be sited in a way that maximises climate, conservation and community benefits and biodiversity enhancement (IRENA Coalition for Action, 2024). These criteria must be developed with input from communities, scientists and other local stakeholders and early on – preferably already in the energy system-planning phase and before concrete projects are planned.

Despite the apparent abundance of renewable energy resources, more detailed assessments of sites earmarked for renewable energy installations often show that an integrated siting process is required. A significant amount of land worldwide is designated as protected areas for biodiversity, and these areas should be expanded in the future in line with the GBF. In addition, there are multiple stakeholders' needs to consider. Lasting sustainable development will be achieved only if nature and stakeholder needs are carefully considered.

Policy pathways

Ecuador is the first country that recognised nature rights in the constitution back in 2008, followed by Bolivia (Berros, 2021). These frameworks require infrastructure developments to align with nature protection and indigenous rights. The nature rights concept originates from Indigenous traditions that emphasise harmony and balance with nature and the community. Such approaches are expanding globally. However, challenges remain on how to reconcile economic and social development with nature protection.

In 2022, the European Union directed member states to map Renewables Acceleration Areas (RAAs) where development will have limited negative impacts on the environment and that will benefit from streamlined permitting (European Parliament, 2022). This was intended to drive harmonised, fair and sustainable implementation of the Renewable Energy Directive. In parallel, member states are also encouraged to (voluntarily) map Grids Acceleration Areas (GAAs) for transmission infrastructure that will support renewable energy designated for the RAAs (European Parliament, 2023). Synergies between mapping of RAAs and GAAs and the plans under the Nature Restoration Regulation (European Commission, 2025) would benefit these processes.

If implemented in a clear, inclusive and comprehensive way, RAAs and GAAs can provide an example of how to achieve the necessary renewable energy infrastructure deployment to meet global climate and energy goals in balance with nature and community needs. The adoption of the RAAs and GAAs can offer a useful roadmap for the required ecosystem-based and community-inclusive spatial planning for renewable energy deployment, as described by the required policies below (WWF, CAN Europe, The Nature Conservancy, Birdlife International, EEB, 2024):

Associated planning should be seen as an opportunity to deliver the necessary renewable energy capacities and infrastructure while contributing to efforts that address biodiversity loss. This planning must ensure an effective selection and designation process that include good governance, stakeholder engagement and public participation. This can minimise impacts on nature, and improve public and stakeholder confidence, which, in turn, reduces the risk of conflicts that could delay developments. A common methodology can ensure the speed, consistency, efficiency and fairness that are required in the approach to rapid renewable energy installation. Associated planning would highly benefit from early engagement with stakeholders (especially affected communities) before formal procedures begin, in order to reduce potential frictions during the planning process.

The selection and designation process should be based on credible, science-based methodologies. They should cover technology-specific energy modelling, wildlife sensitivity mapping, and social and ecological land-use indicators. As detailed in the section on Principle 2, identification of modified areas such as brownfield sites and degraded lands (unless already designated for nature restoration and/or for carbon sequestration) should be prioritised. Such an approach can create opportunities for investment and regeneration in the modified areas, without the need to debate greenfield sites, thus helping to accelerate the installation process. In addition, inclusive approaches to designation processes should be applied, for example integrating the planning of renewable energy with existing or designated land for agriculture, to create multipurpose use in a single area.

Public participation, stakeholder engagement and consultation for the designation of RAAs and GAAs is essential to ensure thorough, effective, inclusive and speedy processes that comply with existing legislative requirements, as expanded in the Overarching Principle 6.

Considering examples of global best practice for renewables development in less sensitive areas for social and environmental impact offers another means to accelerate positive development. It is important to share knowledge and case studies, making relevant datasets and replicable methodologies publicly accessible.

In areas with limited financial resources, renewable energy zoning can rely on existing mapping or open data to identify suitable areas. The International Renewable Energy Agency (IRENA) provides the SolarCity simulator to enable households, businesses and municipal authorities to evaluate the potential for electricity generation using rooftop-mounted solar PV installations (IRENA, n.d.). Involvement of the private sector and targeted support from the international community may help address financial and institutional challenges.

The process should be iterative and continuously adjusted in response to the experience gathered. This will require ***transparent and robust monitoring and review processes*** of the designation and implementation of renewable energy zoning at the outset. Spatial mapping should be undertaken upfront to ensure that the impacts on nature are avoided and minimised, and that there is sufficient public participation and other stakeholder engagement sharing benefits with the local communities.

A growing number of studies provide evidence that there is a path to overcoming the climate, nature and energy challenges we face – and that we do not have to undermine our long-term aims to meet our short-term needs, as showcased in Box 1 (Nature Conservancy, 2020).

Box 1 Smart-siting blueprint in Croatia

Working with the Energy Institute Hrvoje Požar in Croatia, the Nature Conservancy applied its smart-siting approach. They integrated an overlapping series of maps depicting regional environmental and social data with those indicating solar and wind potential. Twenty-two individual datasets were combined to identify ecologically sensitive areas such as bear habitat or bat colonies alongside productive farmland, and zones with high renewable energy potential and proximity to the electricity grid. Input from both local experts and non experts was used to identify land with significant community value.

After excluding areas under strict conservation protection and regions under significant land-use competition, enough suitable land was identified for wind and solar installations in one county to meet half of Croatia's total national 2030 target for solar and wind power. Conducting this analysis for the rest of Croatia could help the country accelerate renewable energy deployment at a crucial time for both people and planet, helping the country to become a green energy exporter in the not-so-distant future.

Principle 2: Co-utilise

This principle prioritises the dual or multiple use of existing structures and modified lands in combination with renewable energy projects.

The following sections detail co-use measures that include solar panels on buildings and car parks; solar and wind projects on degraded lands or brownfields and agricultural lands; and paired with nature conservation efforts. Large-scale projects may compete for land with other uses (Ravi *et al.*, 2016). Co-utilising approaches reduces the need to convert new areas and can help mitigate land-use and resource conflicts while creating synergies and delivering benefits to various stakeholders.

Utilising existing structures

There is significant solar PV potential in urban areas. Rooftop solar installations are the most common example of co-use, integrating solar PV with houses or buildings. Some studies indicate that rooftop solar alone could cover the global electricity needs (Joshi *et al.*, 2021). The EU Energy Performance of Buildings directive will require solar installations in all new residential buildings by 2030 (European Parliament, 2024). The government of India supports the adoption of rooftop solar for the residential sector through a dedicated scheme, PM Surya Ghar: Muft Bijli Yojana (Government of India, 2025). This scheme aims to improve the share of rooftop solar capacity and generate electricity from the residential sector in India. The scheme is expected to add 30 GW of cumulative solar capacity through rooftop installations on 10 million households by 2027. The scheme provides financial assistance to households for installing rooftop solar as well as incentives for utilities and local bodies to promote the scheme and uptake of rooftop solar. In addition to this, various states in India are promoting rooftop solar installation for commercial and industrial consumers through regulatory interventions.

In addition, many houses, offices, public buildings, hospitals, shopping centres and hotels have car parks. Solar panels in car parks offer multiple benefits, including protection for cars and users from heat, rain or snow. In 2022, French law required owners of car parks larger than 1 500 square meters to install solar PV systems (Legifrance, 2023). In Hyderabad, India, a 23-kilometer-long solar PV-covered cycling track was inaugurated in 2023, which has installed capacity of 16 megawatts (MW) (Economic Times, 2023).

Siting on modified areas

Smart siting can use existing infrastructure or identify the many already converted and degraded lands modified by human activity. These include brownfields, such as former industrial sites, manufacturing plants, warehouses and other industrial facilities that may have left behind contaminated soil or groundwater, abandoned oil and gas wells, landfills and waste disposal sites, and former mine lands. Box 2 showcases how landfills can be transformed into energy-generating sites, while Box 3 illustrates utilisation of former coal mining lands (Nature Conservancy, 2025). Siting solar and wind farms on former brownfields can present both risks and opportunities, as the land may be contaminated or have other environmental, technical or regulatory issues that need to be addressed before development can begin (Spiess and De Sousa, 2016). However, these sites often offer advantages such as existing road infrastructure and access to transmission lines, as well as reducing the need to develop and convert natural lands (US Environmental Protection Agency, 2015). Siting renewable energy on former coal mines can support a just transition by helping affected communities transition to a green economy, ensuring they are not left behind in the shift towards a sustainable economy.

Box 2 Solar PV siting on landfill in Australia

Landfills, including after closure, have limited alternative uses available due to their long-term earth settlement issues and environmental controls. However, these sites can be transformed into valuable renewable energy hubs, including through solar-on-landfill technology.

Landfill biogas, arising from the natural decomposition of waste, can be captured and used to generate valuable synchronous renewable energy while also significantly reducing methane emissions to the atmosphere. Offering synchronous, flexible and dispatchable renewable energy, this bioenergy can enhance local energy reliability. Solar energy, when co-located with power generation from landfill biogas, can enjoy the advantages of leveraging existing electrical infrastructure to provide a sustainable and economically viable use for otherwise restricted land.

LMS Energy has pioneered solar on landfill in Australia. For example, this hybrid renewable energy generation approach has been successfully implemented working with the Albury City Council at the Albury Landfill in New South Wales, where LMS has developed a 1.5 MW solar farm alongside a 1.1 MW landfill biogas power generation facility to maximise land-use efficiency. Together, these systems produce renewable electricity for approximately 5 000 residents annually. It showcases the potential of landfills to support the clean energy transition while also mitigating greenhouse gas emissions, contributing to a low-carbon future.

Solar park on the landfill site

Box 3 Former coal mining lands converted to solar in the United States

The Appalachians, a chain of mountains on the eastern side of the United States, are covered in forests rich in biodiversity. The local economy in the region used to be based on coal mining. As the coal mining industry declined, unemployment increased and degraded land was left behind.

The Nature Conservancy, in partnership with Dominion Energy, Sun Tribe and Sol Systems, are collaborating to develop solar energy on the degraded former mine lands in the Cumberland Forest region. When issuing the request for proposals (RFPs) to solar developers, The Nature Conservancy specified that only projects on former mine lands would be considered. The Nature Conservancy had conducted a Preliminary Site Suitability Analysis for Solar Development that identified compatible and non compatible areas for solar development in order to protect "forest and ecosystem health." The RFP also asked that proposals specify how they will engage with and provide environmental and economic benefits for the local community.

Potential economic benefits identified in the RFP included permanent and temporary local jobs, training programmes, local hiring commitments, and support for community funds. Environmental measures were proposed, such as wildlife-friendly fencing, incorporating native pollinator plants, sediment control and more.

So far, a combined 140 MW of solar as well as utility-scale battery energy storage systems will be built on land used formerly for coal mining. In addition to the economic benefits brought to the community by these projects, by building on these degraded lands, the projects avoid impacts to the biodiversity-rich forests.

Agrivoltaics and aquavoltaics

The simultaneous use of land for agricultural and electricity production is gaining traction around the world. Japan, as a pioneer and the country with the first legal framework for agrivoltaics, had already installed more than 5 000 agrivoltaic projects as of March 2023 (IRENA Coalition for Action, 2025). Other countries such as the People's Republic of China, the United States, France, Italy, Germany and India are realising the potential of the dual-use approach and are starting to establish policies and regulations for scaling up agrivoltaics. As an example, covering just 1% of the utilised agricultural area of the European Union with agrivoltaics would be enough to surpass the EU solar PV target for 2030 (JRC, 2023). The Government of India launched the Pradhan Mantri Kisan Urja Suraksha evam Utthan Mahabhiyan (PM-KUSUM) Scheme to solarise India's agricultural electricity use (Government of India, 2024). The scheme aims to reduce carbon emissions and air pollution from irrigation in the agricultural sector, which was dependent on diesel pumps, with an ambitious goal of solar capacity of 34.8 GW by March 2026. The scheme also provides capital subsidies and debt financing options for implementation of solar PV in the farm sector.

In contrast to ground-mounted solar PV on agricultural land, agrivoltaics allow for continuous use of the land for crop production (*e.g*. lettuce, blueberries or grapes) or grazing (*e.g*. sheep or cows). Beyond generating electricity for irrigation water pumps, cooling and storage, agrivoltaics can provide additional benefits for agricultural production such as protection against extreme weather or reduced irrigation needs due to shading. Crop choice and design of the agrivoltaics system need to be adapted and optimised for local conditions to maximise the benefits of agrivoltaics. Agrivoltaics can help tackle some of the pressing societal challenges such as regional decarbonisation, revitalisation of rural areas by diversifying and increasing the income of farmers, increasing national food and energy security, and strengthening disaster resilience by locally providing electricity to affected communities in times of power outages. Moreover, agrivoltaics can be designed to increase biodiversity, for example, by planting flower strips for endangered insects under vertically installed solar panels. Box 4 describes fishery and solar PV integration in China which enables more efficient utilisation of land resources (IRENA Coalition for Action, 2025).

Box 4 The Dongying fishery-solar project in China

Tongwei New Energy developed the Dongying fishery-solar project in China combining ecological aquaculture with solar panels. This model achieves more efficient utilisation of land resources allowing for the simultaneous production of food and energy on the same area, thereby maximising land-use efficiency and addressing both energy and food security concerns.

The rapid expansion of solar PV in China has led to increasing challenges related to land use. The dual use strategy can effectively alleviate land pressures while delivering additional benefits. The fishery-solar project has boosted shrimp and sea cucumber yields by 50% owing to improved pond conditions through better temperature regulation and reduced algae growth. The shading effect of the solar panels stabilises pond conditions, creating a more sustainable aquaculture environment. The project achieved a "threefold harvest" of fishery, electricity generation and environmental protection.

Principle 3: Conserve, restore and enhance

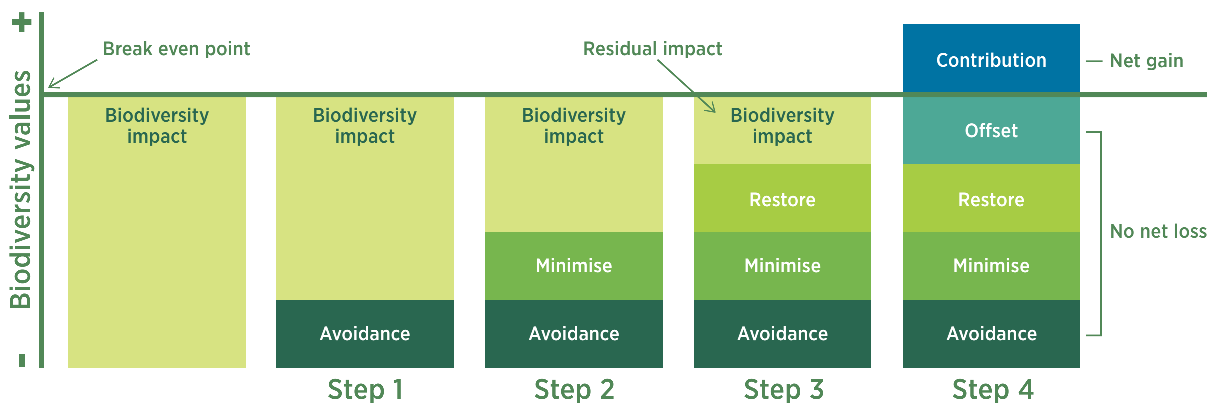
This principle requires proactive planning: conserving ecosystems as much as feasible, restoring development impacts to the extent possible and implementing measures to enhance biodiversity.

Environmental considerations should be included as part of the strategic planning process, influencing site selection, preparation, design and operation, and decommissioning.

Potential impacts on biodiversity should be managed using the mitigation hierarchy framework of avoidance, minimisation, restoration and offsetting, as outlined in Figure 5 (Bennun *et al.*, 2021):

1. **Avoidance.** The most effective action refers to measures that anticipate and prevent any impacts on biodiversity.
2. **Minimisation.** This measure reduces impacts that cannot be eliminated.
3. **Restoration.** This step entails measures to repair impacts done by the project.
4. **Offsetting.** Biodiversity offset should achieve measurable conservation outcomes that result in no net loss and preferably nature-positive outcomes; in other words, a net gain of biodiversity.

Figure 4 Mitigation hierarchy



Source: (Ecology by Design, 2022).

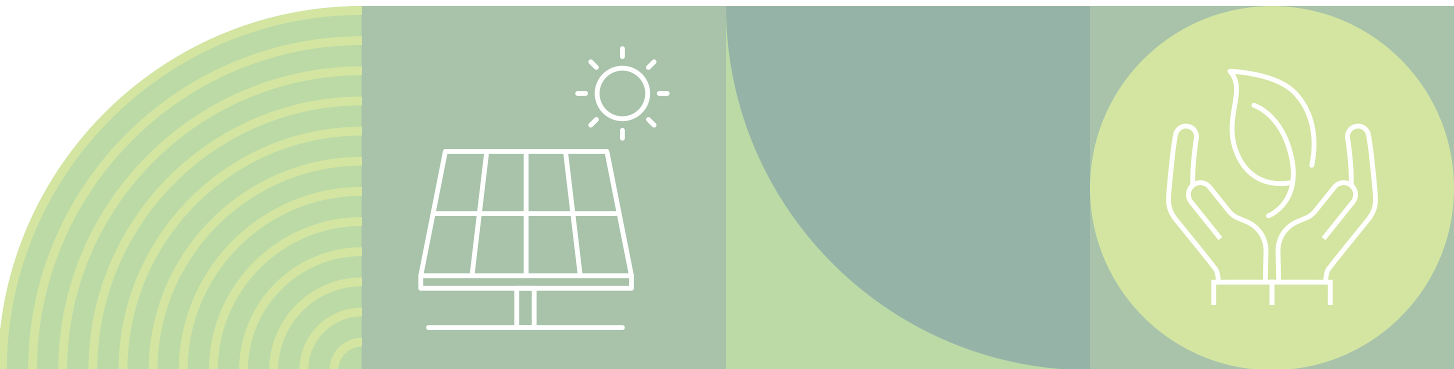
Renewable energy developers have the opportunity to be strategic in considering alternative methods for construction and operation not only to meet the basic requirement of environment protection, but also additionally advance their environment, society and governance (ESG) outcomes. Opportunities include reducing their environmental impacts and utilising the biodiversity resources present on-site to improve energy outputs and reduce construction and operational costs as described in the following subsection.

In terms of power grid development, early-stage planning is essential to minimise environmental impacts and subsequent conflicts. Recent studies highlight innovative approaches to balancing electricity grid expansion with environmental protection. In China, researchers propose an adaptive management approach that includes flexible route layouts, ecological corridor planning, sustainable vegetation restoration and biodiversity conservation measures to minimise ecological disruption and respond to changing environmental conditions (Yin *et al*., 2025). A study from Brazil promotes sustainable electricity grid routing introducing five environmental criteria and eight engineering criteria suitable for spatial representation as geographic information system (GIS) layers, allowing spatially explicit transmission line route modelling (Biasotto *et al*., 2022).

Importantly, a baseline study should take place as part of the planning processes, to gather information regarding the state of the area prior to development of the project against which the predicted impacts should be measured (Biodiversity Company, 2023). One of the most important stakeholders to ensure the effective implementation of conservation and restoration measures is the local community, as described in Principle 6. Ecosystem conservation and restoration have multiple environmental and socio-economic benefits, as detailed in Table 1 (Kakani *et al*., 2024).

Table 2 **Conservation and restoration activities and benefits**

<table>
<tr><th></th><th>Conservation and restoration measures</th><th>Benefits</th></tr>
<tr><td>1</td><td>Siting and permitting considerations based on impact on local flora and fauna</td><td rowspan="6">• Reduced erosion and the ambient air temperature, improved site drainage.
• Reduced development and operating costs.
• Increased pollinator abundance and biodiversity.
• Community support and incentivisation to conserve and restore ecosystems near site.
• Reducing conflict risk potentially shortening project timelines.
• Sound environmental practices.</td></tr>
<tr><td>2</td><td>Preserving native species (flora and fauna)</td></tr>
<tr><td>3</td><td>Restoration activities in the construction plans, such as minimising removal, and replanting native species</td></tr>
<tr><td>4</td><td>Enhancement measures such as planting pollinator-friendly plants between solar panels and integrating solar panels and green roofs</td></tr>
<tr><td>5</td><td>Community and other stakeholder engagement while planning to ensure their participation, community benefits and ownership schemes</td></tr>
<tr><td>6</td><td>Decommissioning and ecosystem restoration plans which ensure complete dismantling and collection from site</td></tr>
</table>



Conserving and restoring vegetation benefits

New thinking on energy project design, development and operation considers the value offered in natural systems and aims to achieve benefits for both renewable energy and the environment. For solar energy, native vegetation, whether retained or added to the site, has the potential to reduce the cost of site preparation and improve panel energy production and site drainage, stability and biodiversity. Embracing a change in standard site preparation techniques and typical management practices requires planning and the identification of site-based limitations. However, it offers the potential to change the green metric and sustainability of a site, increasing energy production and considerably reducing development and operating costs.

When considering utilising vegetation cover on site, two broad approaches promote a reduced impact to vegetation: 1) vegetation retention with biomass reduction to support construction; and 2) site or vegetation removal and site levelling with native vegetation establishment following construction. Both options will provide environmental and physical benefits to a solar farm and increase the alignment with the ESG responsibilities of a project. Vegetation or biomass reduction of a site, as an alternative to vegetation removal, can be achieved through rolling, slashing or flail mowing. This minimisation strategy supports regeneration and the use of native vegetation. The processes aim to reduce site disturbance and allow the regeneration of a site following solar array installation. The ability to use these techniques is dependent upon topography, vegetation type, and plant density. The initial site preparation methods selected for either retaining or clearing and establishing cover under panels will determine the types of long-term vegetation management requirements. The benefits are detailed below.

- **Ambient temperature**

  Ambient air temperature influences panel function, affecting operational efficiency. With increasing temperatures, panel outputs can reduce by 10-25%. The cooling effect of transpiring plants in integrated PV-green roof systems is well documented, whereby outputs were recorded to increase by up to 8% (Lamnatou and Chemisana, 2015). Maintaining low-stature plants beneath panels may positively influence microclimate, reducing temperature as well as increasing humidity. Vegetation cover will contribute to the deposition and build-up of organic matter. Soil carbon supports soil health and increases moisture retention, which in turn supports reduced ambient temperature. In contrast, bare soil can act as a thermal source, increasing temperatures and adversely impacting panel production.

- **Dust management**

  Typically, solar farm site preparation involves grading, removing all vegetation and the biological soil crusts (BSCs). These flat, open areas facilitate machine and plant movement on site and allow for efficient construction activities. However, this approach also creates dust pollution, which is detrimental to people and solar panel function. An alternative tool for managing dust can be found in nature. Low-growing native vegetation can be used as a form of site stabilisation. This vegetation provides a range of services that support site stabilisation including root systems that bind soil particles together, increased soil porosity to improve drainage, cover for the soil surface to reduce the erosive impact of rain and a rough surface to reduce fetch (the distance over which wind has blown without obstruction), reducing wind speed and erosive potential. In arid landscapes, BSCs in combination with low-lying vegetation play an essential role in soil stability, carbon cycling and water penetration. BSCs are a community of living organisms including moss, liverworts, lichen and bacteria, and have important functions, such as fixing nitrogen, increasing soil fertility, absorbing rainfall, decreasing runoff, binding soil and reducing erosion. The maintenance of the BSC along with low-lying vegetation cover provides the opportunity to reduce dust production during site preparation and over the operational life of a solar farm.

- **Weed management**

  The retention of native vegetation on a solar farm site provides the benefit of reduced weed management requirements. A completely cleared site provides a fresh surface for opportunistic weed species, which can rapidly colonise disturbed areas. Weeds can easily get out of hand in response to a large rainfall event and reach a size that will overshade panels and impact production, and once they dry, can pose a fire hazard. The right site preparation methods and suite of native species can provide competition that will significantly reduce the growth of weeds.

- **Biodiversity**

  The retention of native vegetation or establishment of vegetation on a solar farm site supports the maintenance of biodiversity and provides a range of environmental benefits. Solar farms can provide habitats and corridors for the movement of fauna species without reducing solar panel function. For example, construction with corridors of vegetation between every second row to maintain stretches of low habitat may be used by a range of fauna.

  While this biodiversity enhancement can be seen through an ESG responsibility or conservation lens, fauna species can also provide ecosystem services on-site that actually benefit a solar farm. For example, reptiles create small burrows that can contribute to the soil's capacity to absorb heavy rains. Organisms can support soil health, such as breaking down plant matter, increasing porosity and protecting against diseases.

- **Drainage and erosion**

  Climate change is expected to increase the frequency of intense rainfall events. The ability of soils under a solar farm to absorb large amounts of water while minimising erosion will increase in importance moving forward. Low vegetation cover, a healthy BSC and wildlife under a solar farm can improve soil drainage and reduce water-based erosion through a range of features. A functioning ecosystem has an enormous amount of drainage capacity derived from root systems, animals' burrows and the honeycomb of air pockets created by invertebrate activity. In addition, vegetation soaks up water and their root systems hold soil particles together, improving site stability.

- **Costs**

  The preparation of a solar farm has considerable costs associated with it; for example, the type of machinery required to carry out site preparation impacts project costs. Biomass reduction and vegetation retention instead of removal can result in long-term reduction in machinery costs (McCall *et al.*, 2023). A further reduction in costs can be obtained by reducing the amount of soil to be managed or dumped and the number of water trucks required for dust management. Proactive planning of site preparation and management of vegetation can reduce the maintenance of a site over time, increase the benefits and reduce the costs of vegetation management at the site.

The case study in Box 5 illustrates that there are co-benefits that could be utilised to support both industry and the environment and provide considerable added value for both (Government of South Australia, 2021).

Box 5 Native vegetation co-benefits approach in South Australia

Three developers in South Australia applied the co-benefits approach. SIMEC Energy Australia worked with Succession Ecology to experiment with a site preparation technique that avoided grading and used rolling. They found that vegetation was able to regenerate to its original diversity and cover within three years. SA Water successfully applied native seed to establish low ground cover under their solar farms in semi-arid ex-cropping sites.

Iberdrola worked with Succession Ecology to utilise the biomass reduction technique on a large scale to reduce their impact on native vegetation and the BSC and support the natural regeneration of low native vegetation cover. This was a world-first application of this method at such a large scale (about 120 hectares) at the time, and it won Iberdrola the South Australian Premier's Award for Energy and Mining – Innovation in Environment in 2021.

Developers should aim to integrate solar and wind projects with active measures to enhance biodiversity and nature conservation. Box 6 illustrates a solar project in Brazil that integrates forest restoration. Projects that incorporate nature restoration and enhancement measures can also achieve higher community acceptance as Box 7 demonstrates (Renewable Energy Magazine, 2024; ScottishPower Renewables, 2025).[1] Financial institutions can provide technical assistance and put a pressure on developers by adapting environmental standards. Corporate sourcing of renewables could incorporate criteria to ensure that companies buy renewable energy from projects that avoid negative impacts to wildlife and habitat, thereby supporting sustainability goals for climate and nature.

Box 6 Mendubim project preserving native species and restoring forest in Brazil

Scatec, a Norwegian renewable energy company, operates the 531 MW Mendubim solar project in the state of Rio Grande do Norte. The project in partnership with Equinor and Hydro Rein will help to power the equivalent of some 620 000 households in Brazil.

As part of the project, Scatec carries out forest restoration in an area of 180 hectares of the Caatinga biome, planting approximately 300 000 native seedlings. Given that the Caatinga region faces challenges related to water scarcity, the planting is being carried out in three phases during the rainy season. This approach minimises the risk of plant mortality without the need for irrigation during the planting process. The third and final planting phase is scheduled for completion in the first quarter of 2025. Following this, the area will be monitored for at least three years to ensure the environmental conditions of the site are maintained.

The planting is being conducted in the same state where the Mendubim Project is located (Rio Grande do Norte) in an area previously degraded by agro-pastoral activities. To support the forest restoration process, Scatec partnered with local organisations that are managing the entire process – from seedling production and soil preparation to planting. Additionally, members of the local community received training so they can actively participate in the planting activities, fostering local capacity building and community engagement.

[1] Unless otherwise noted, this and all currency figures that follow are in 2025 USD.

Box 7 Whitelee Wind Farm restoring peatlands in the United Kingdom

ScottishPower Renewables, the United Kingdom (UK) renewable energy developer, operates the Whitelee Wind Farm near Glasgow, Scotland. It is the largest on-shore wind farm in the United Kingdom, spanning 83 square kilometers and hosting 215 wind turbines, each with a capacity of 2 MW.

As part of the project, over USD 1.8 million were invested to restore more than 1 000 hectares of peatlands. Peatlands restoration recreates a healthy habitat for wildlife, reduces flooding risks, improves water quality and can store the equivalent of 3.6 million tons of carbon dioxide. The Royal Society for the Protection of Birds Scotland awarded ScottishPower Renewables a Sustainable Development Award in 2016 for industry-leading peatland restoration techniques.

The wind farm also offers environmental education and recreational opportunities for the local community, including a visitor centre, walking trails and mountain biking paths. Such approach enhances local acceptance of the project by demonstrating clear benefits to the communities and environment.

Principle 4: Monitor and adapt

This principle highlights the need for monitoring the potential impacts of the project during construction, operation and the end-of-life phase, making adjustments in response to new information.

Ecosystems are dynamic and complex. Technologies for adaptive management should be used to adjust to emerging evidence of wildlife movement or plant growth. It is vital to cover the entire life cycle and beyond to generate a holistic picture of possible impacts to ecosystems and communities. The scope and extent of monitoring depend on the specific technology (*e.g.* onshore wind, offshore wind, PV) to account for the technology-specific applicable legal or lender requirements and regulations on one hand, and best possible practices on the other hand. As a general principle, monitoring should follow a holistic view and the use of both local/bottom-up data (*e.g.* INaturalists, camera traps, eDNA) and top-down approaches (*e.g.* remote sensing, ENCORE and IBAT tools). A holistic view helps to get a general view of potential impacts before, during and post-construction.

Impact pathways that are generally monitored in the natural environment are habitats, biodiversity and species (*e.g.* birds and bats, marine mammals, reptiles and amphibians, insects) emissions, soil and seabed, water quality, and others. Social factors that are part of assessments include spatial use and land ownership rights, Indigenous rights and cultural heritage, socio-economic impacts, and public health.

An environmental impact assessment (EIA) or environmental and social impact assessment should be mandatory for a developer to paint a comprehensive picture of possible impacts, both during construction and operation and increasingly also for end of life.

Policy pathways

German legislation sets monitoring requirements for renewable energy projects under the Federal Nature Conservation Act. Sector-specific regulations such as the spatial development plan for offshore wind in the North Sea and Baltic Sea mandate extensive monitoring of potential negative impacts to the environment for projects in development and operation. This includes monitoring of impacts on key species groups, habitat integrity, material and non material emissions to the environment, and cohesion of landscapes or regulatory functions of ecosystems. This is tied directly into the permitting process. Projects that do not adhere to set monitoring requirements are unlikely to obtain consent by the regulators.

In South Africa, the National Environmental Management Act (NEMA) requires developers to include environmental management programmes with monitoring components in project proposals. The focus is set on endemic and threatened species as well as bat and bird monitoring with specialised bird radar systems, given the country's rich avian diversity.

Advanced tools and technologies to improve monitoring efforts have emerged in recent years. Artificial intelligence (AI) holds a great potential to improve biodiversity outcomes, as described in Box 8 (Masdar, 2024).

Box 8 Artificial Intelligence protecting birds in a wind farm in Uzbekistan

The 500 MW Zarafshan wind farm in Uzbekistan is the largest in Central Asia, containing 110 wind turbines. It is located in the area where birds of prey breed and other numerous species migrate. Wind turbine blades can disrupt bird habitats by creating risks of collision. Masdar, the United Arab Emirates-based company, applied AI technology for biodiversity protection at the wind farm. The technology detects birds flying in the vicinity and automatically shuts the wind turbine down if there is a risk of collision, turning the turbine back on once it is safe. This technology demonstrates how wind energy can be generated while safeguarding biodiversity.

Principle 5: Extend the useful life

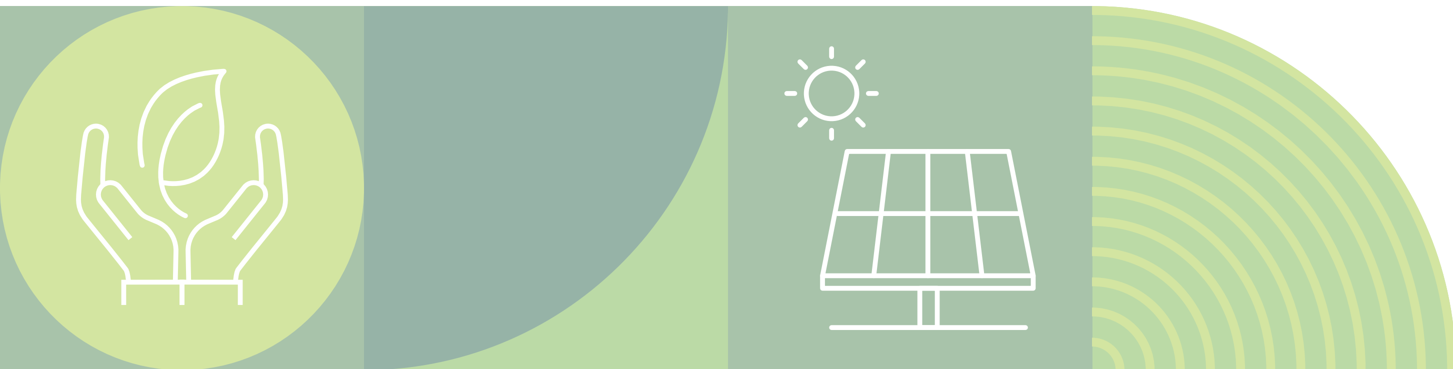
This principle focuses on extending the useful life of already existing renewable energy installations to minimise environmental impacts.

Cumulatively, renewable power capacity sits at over 4 448 GW – with many earlier projects facing end of life (IRENA, 2025). Onshore wind energy, for example, has an end of life of 20 years for older turbines, meaning that approximately 178 GW of onshore wind energy would need to be decommissioned or repowered by 2030 (IRENA Coalition for Action, forthcoming). Decommissioning would decrease energy security, impact lives and livelihoods, and lead further away from the climate targets.

Existing projects are already connected and located in areas with excellent renewable resources. As such, extending the lifespan through proper maintenance, retrofitting and repowering by replacing solar panels and wind turbines with more efficient models offers a solution that limits the need for new land use and connections, subsequently minimising environmental impacts. The steps for extending the useful life and minimising environmental impacts are described below:

Maintenance

This refers to proactive measures to maximise the lifespan and output of renewable energy projects. In addition to measures to optimise performance such as regular cleaning, monitoring and check-ups for faults, native vegetation can be beneficial to prevent overheating and dust, as described under Principle 3: Conserve, restore and enhance.



Refurbishing and retrofitting

The viability of refurbishing and retrofitting a project's component(s) should be assessed, as this can present a lower-cost option with less environmental impact than fully decommissioning and repowering projects (IRENA Coalition for Action, forthcoming). Refurbishing and retrofitting for onshore wind projects, for example, entails upgrading older turbines or specific components such as blades, rotors, gearboxes and hubs with more advanced technologies, while retaining some existing parts such as the foundation and tower. Refurbishing can be completed over a few months, extending the project site's operation for a few more years, with the upgrades potentially increasing the energy output of the facility.

It should be noted that, given technological advancement, it will not always be the most efficient option due to outdated parts, and then repowering should take place. The challenges of refurbishing and repairing are primarily economic, as there is a need to identify profitable models and incentives, and related to trust – a lack of confidence in the long-term robustness of repaired components (REN21, 2023). Certifications, standards and technical training could enable broader applications of refurbishing and retrofitting.

Repowering

Historically, older renewable energy projects are located in the best resource-rich places. Once solar and wind technologies reach their end of life (where refurbishing and retrofitting are no longer feasible options) the decommissioning of the technologies and repowering of the existing sites with new more efficient panels or turbines should be undertaken. Repowering leverages existing infrastructure, grid connections and land agreements, and existing community support and optimises the existing site, as it reduces the need for additional land for new renewable energy project sites and the need for new infrastructure (IRENA Coalition for Action, forthcoming).

In addition, ongoing innovations and technology enhancements towards renewable technology features such as more efficient solar panels or increased wind turbine hub heights or rotor diameters can increase energy yields for the same location – further decreasing the need for new greenfield developments. Repowering also ensures local community beneficiation can continue, and environmental best practices within the existing site continue to be upheld.

For onshore wind projects, which typically reach end of life at 20 years for example, repowering involves replacing all components of a wind turbine system; this includes completely dismantling and replacing turbine equipment of an existing wind energy project including the tower and foundation, a process that could take nearly two years to complete. To minimise downtime, repowering of the wind farm can be performed in phases. Despite the increase in the height of the turbines, the relevant reduction in the number of turbines and distance between them reduces the overall impact on the landscape along with a potential reduction in social opposition from nearby localities, as well as the need to acquire and impact new areas. New turbines are designed more efficiently and reduce noise pollution compared with older turbines, benefiting communities and biodiversity. Box 9 showcases the example of repowering small-scale installation in India.

Box 9 Repowering wind in Tamil Nadu, India

Wind power in India witnessed rapid development beginning in the mid-1990s, driven largely by a supportive policy environment, such as the Generation-Based Incentive scheme, tax exemptions, and feed-in tariffs. Tamil Nadu, owing to its advantageous wind corridors and early policy initiatives, emerged as a leader with an installed wind capacity of 11.7 GW as of March 2025. Most of Tamil Nadu's installed capacity dates back to the early days of wind power development and is based on older technologies with declining efficiency, increased downtime and heightened safety risks. They occupy vast stretches of prime wind sites but fail to deliver optimal power output. Repowering is a necessity that offers the dual benefit of increasing renewable energy output and unlocking the full potential of already-utilised sites.

Tamil Nadu accounts for nearly half of India's textile market. Textile mills benefited from government support to modernise using wind energy to stabilise their costs and power supply. In the early 2000s, Narasus Spinning Mills, a company producing cotton yarn, installed three 250 kilowatt (kW) turbines. Over time, the turbines began to fail due to a lack of spare parts and maintenance support.

In 2021, a detailed feasibility assessment was conducted. While the original plan was to upgrade to 500 kW turbines, this was not possible due to constraints in the service connection capacity. Ultimately, Narasus chose the Siva 250/50 turbine, featuring pitch control systems to adjust blade angles and optimise rotor speed for better energy output. With the necessary No Objection Certificate from neighbouring turbine owners secured, the company proceeded with reinstallation at the same site. Since repowering, the annual generation more than doubled, demonstrating how repowering can restore efficiency and reliability. However, targeted policies, stakeholder support, and private sector participation are necessary to fully enable repowering in the region.

Newly commissioned 250 kW turbine at Karungulam

Photo credit: Centre for Science and Environment

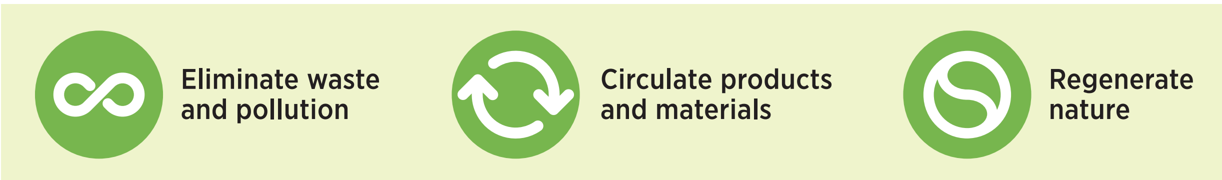
Decommissioning: Conservation and restoration measures

After project completion, the site can either be repowered or decommissioned and restored. While repowering can often lead to better outcomes for climate and nature and should be prioritised, project planning must also account for decommissioning and site restoration at the end of the project's lifespan. This should include approaches for waste management, planning financial implications, defining roles and responsibilities, etc. Planning should give clarity to the local governments, communities and other stakeholders on the future of the site post-project completion. Over the years, local communities and the ecosystem might grow dependent on the renewable energy project and the end of the project might lead to some unintended consequences. For example, some studies highlight positive effects of solar PV on water-stressed land, for some crops and animal rearing (WEF, 2023). Lack of decommissioning, site restoration and waste management could contaminate the environment and pose health and safety hazards (Invernizzi *et al*., 2020). Each project site and renewable energy technology will need a tailored approach and assessment of impacts on biodiversity of decommissioning versus maintaining the infrastructure to restore the site post-decommissioning. As such, project development plans need to include considerations to the site decommissioning at the early stages.

Circular economy

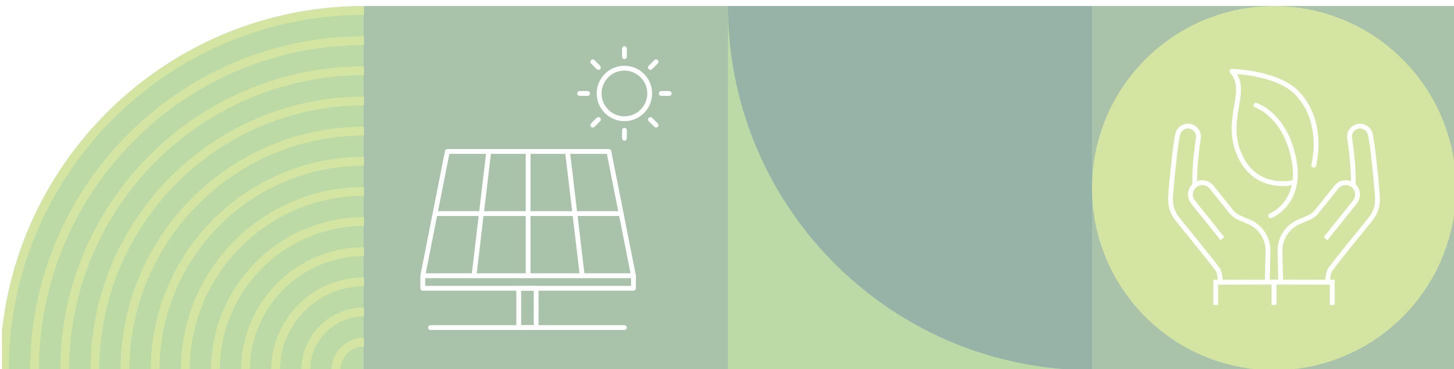
Circular economy principles should guide optimised material and energy use (see Figure 6). Companies would need to focus on applying a circular approach to minimise the use of primary materials and maximise the reuse and recycling of materials while ensuring ethical sourcing of raw materials across their supply chains as well as managing impacts related to the disposal of end-of-life equipment.

Figure 5 **Circular economy principles**



Source: (Ellen MacArthur Foundation, 2021)

Significant changes and proactive enforcement are also needed in relation to critical minerals for developing increased energy storage capacity and infrastructure to avoid the degradation of natural habitats and other harms. Box 10 describes the circular economy initiatives by Enel Green Power across solar and wind technologies (Enel, 2023).



Box 10 Zero Waste initiative in Chile and beyond

In 2020, Enel Green Power, the multinational renewable energy company, launched its Zero Waste initiative, which aims to reduce waste on construction sites and at plants by maximising reuse, improving recycling and promoting good practices in collaboration with contractors and local communities.

The innovation team is actively exploring ways to implement circular management of renewable technologies across their cycle, especially as they reach end of life. Solar and wind infrastructure is particularly relevant, anticipating their decommission from 2030 onwards.

For solar, the Photorama project recovers valuable materials from photovoltaic panels to reuse them in the production chain. In Chile, the 2nd Life project investigates PV module failures and explores how disused panels can be reused in new ways.

For wind energy, the Wind New Life project is testing the technical and industrial-scale feasibility of recycling wind turbine blades. Other pilots are assessing integration of shredded blade materials across different sectors. These efforts are developed with other utilities and sector associations to inform broader advocacy on sustainable decommissioning.

Enel has also launched a New Life programme for equipment and spare parts, aimed at repurposing items from decommissioned plants, warehouse stock and repowering projects. Parts are either reused internally, sold or recycled.

Overarching principle 6: Engage local actors

Engaging and involving communities and local stakeholders is essential from the earliest stages and throughout all phases of the project. Robust participatory processes achieve legitimacy and public support, integrate local knowledge, and ensure that local stakeholders gain benefits.

Each of the five principles described above must incorporate community and local actors' engagement and participation in the decision-making process. All these aspects need to gain social acceptance. Incorporating local knowledge is beneficial to avoid ecologically sensitive and culturally significant areas and minimise disruption. Community engagement should be inclusive and tailored to local circumstances, ensuring meaningful participation of women, youth and marginalised communities. This approach also ensures fair benefit sharing with local communities and mitigates conflict risk (IRENA Coalition for Action, 2024).

Local communities are usually users, beneficiaries or trustees of land on which a renewable energy project is to be permitted, so their support can enable better conservation and restoration practices. Developers and governments may lack local knowledge and skills to efficiently undertake conservation and restoration activities, and these aspects of the project could be driven by communities and other local stakeholders. This engagement should lead to incentives for communities to ensure development of renewable energy as well as conservation and restoration of local ecosystems. While giving responsibility to communities, the project should also lead to direct benefits such as establishment of social infrastructure and economic development of the region. This will ensure that environmental as well as socio-economic benefits and costs of the project are distributed across multiple stakeholders.

All infrastructure projects, including renewable energy projects planned at any location, have an interplay with local socio-economic and environmental aspects. Their role in shaping the local economy and ecology needs to be recognised by stakeholders engaged in siting and permitting, as projects gain acceptance but also build social cohesion. The community has a local context understanding and is directly affected by all aspects of local resource use. When renewable energy projects make use of local natural resources, such as land, water and biodiversity, community engagement is key to the success of the project. The siting and permitting assessments for renewable energy projects should go beyond technical and financial parameters, to include local social performance and community needs (IRENA Coalition for Action, 2024).

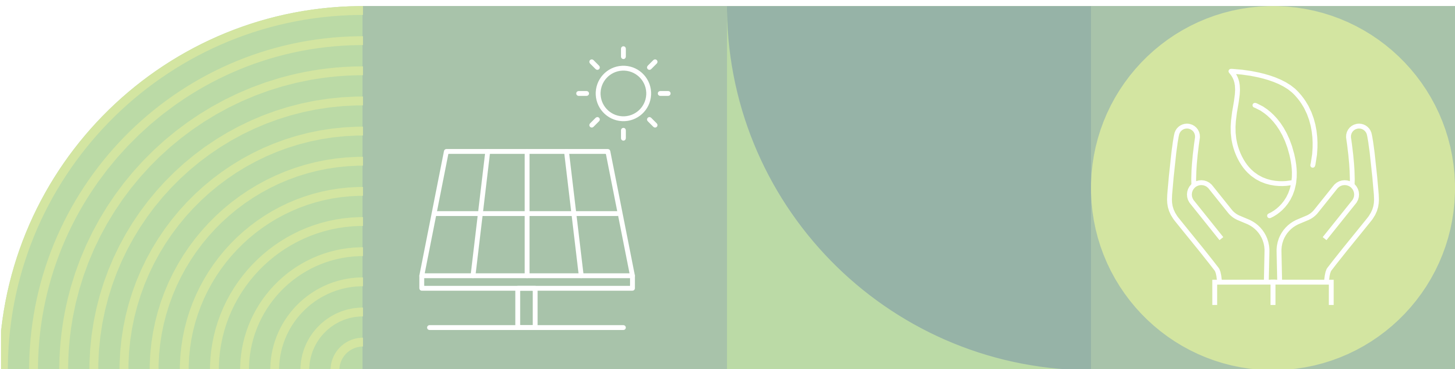
Policy pathways

Local stakeholders tend to participate and accept projects' development if they feel they are part of the process (IRENA Coalition for Action, 2024). Communities and local actors should be able to influence decisions during planning and share the benefits during operation. Engaging communities early on fosters collaboration, reducing risks of conflicts and legal challenges resulting in costly delays.

A number of policies exist that mandate appropriate community engagement. Free, Prior and Informed Consent (FPIC) is a right recognised by the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP), the Convention on Biological Diversity and the International Labour Organization Convention. For example, in Sierra Leone the law requires FPIC for any industrial project (SierraLii, 2022). The Canada Indigenous Rights Framework also mandates FPIC for projects on their lands, including renewable energy (Government of Canada, 2021). Key aspects of the community engagement should include:

- Public participation exercised as early as possible.
- Informal engagement with stakeholders in parallel to mandatory requirements, when possible.
- Public engagement should be transparent, tailored to local cultural and social contexts, and accompanied with easy-to-access and clear information, especially when considering complexities of siting and permitting procedures.
- Effective involvement and consent, FPIC, complaint mechanisms, consultation routes for local communities/indigenous populations and making them active decision makers.
- Co-ownership and benefit sharing with local communities.
- Incorporating local knowledge to benefit the renewable energy project and communities.
- Communicating expected and actual environmental and socio-economic aspects of the project and seeking ways to minimise impacts while maximising benefits.

Box 11 illustrates how collaboration between developers and local communities can achieve renewable energy expansion while preserving the environment. Box 12 showcases how good data and comprehensive stakeholder engagement can achieve public support for electricity grids (Ruiten *et al*., 2023).



Box 11 Collaboration to preserve wetland next to solar PV project in Japan

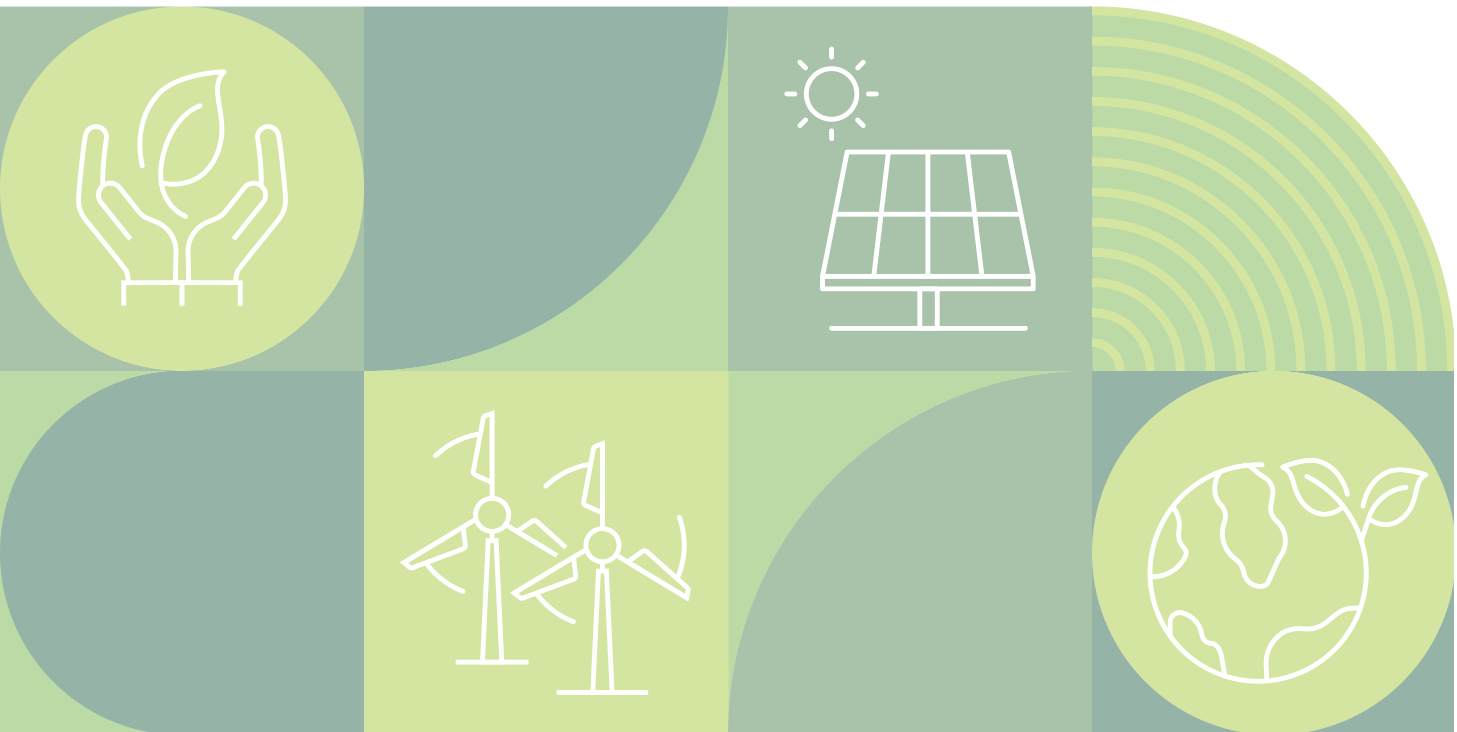
In 2017, a 2 MW solar PV project was proposed near a residential area in Gifu Prefecture, Japan. The project was opposed by residents' groups because the proposed site was located near the residential area and included a wetland with rare plant life. After repeated discussions between the project developers and the local residents, they agreed to preserve the wetland and to reduce the installation area of PV panels. The PV plant was completed in 2019.

The local residents then formed a new group to preserve the wetland. The new group built a boardwalk to observe the wetland and provides nature observation programmes for local elementary school students. The project owner also co-operated in the construction of the boardwalk and contributed to the protection of the wetland. The wetland was certified as a Nationally Certified Sustainably Managed Natural Site by the Ministry of Environment in 2023 and registered as an OECM (Other Effective Area-Based Conservation Measures) in 2024.

Box 12 Co-design process in grid infrastructure siting in the Netherlands

As part of the Dutch government's effort to improve connectivity near offshore wind farms, TenneT (the German-Dutch transmission system operator) developed the South-West 380 kilovolt east electricity grid in the Netherlands in 2008. For this project, TenneT implemented a co-design process involving the public and various stakeholders in decisions regarding infrastructure siting. This included selecting the power line route, determining specific connection points, and collaboratively designing criteria and assessment ideas for the EIA.

Approximately 700 citizens participated in open information sessions and work studios, providing input on concerns, preferences and potential bottlenecks along the route. As a result of this engagement, one section of the route was altered, and a new pylon design was adopted following the co-design process. The outcome was well-substantiated and practical, and stayed within budget, while also receiving broad public support.



04 Challenges and barriers

All stakeholders involved in adopting and implementing the above-mentioned principles and recommendations in siting and permitting processes may face challenges. This section highlights common factors and constraints for integrating nature considerations into renewable energy and grid infrastructure siting. Addressing or mitigating these barriers is crucial for ensuring that renewable energy not only sees increasing shares in the global energy mix, but that with increased deployments the preservation of ecosystems and the well-being of communities is guaranteed, especially in emerging markets and developing economies.

Lack of data and low awareness

One major challenge is the general lack of data related to local ecosystems and biodiversity. This limitation hinders the ability to conduct thorough EIAs and makes informed site selection difficult. Additionally, there is often a lack of awareness among policy makers, developers and the public about the critical intersection between renewable energy deployment and ecosystem health and community well-being. While renewable energy is seen as essential for reducing carbon emissions, the cumulative impacts to ecosystems and communities are not yet fully understood and require more data and analysis.

Although investing in data collection and awareness campaigns requires upfront costs, this approach helps prevent long-term environmental degradation and financial losses. Increased awareness can lead to more informed decision-making and stronger public support for projects. Funding is necessary for ecological studies focusing on cumulative effects and to finance capacity-building programmes.

Political will

Successfully incorporating environmental best practices relies significantly on political commitment. Governments and involved regulators and agencies need to demonstrate the political will not only to advance the energy transition but also to ensure that renewable energy projects advance environmental and community values.

Strong political commitment can streamline regulatory processes, reduce conflicts and enhance international credibility. The long-term benefits of sustainable development generally outweigh the short-term costs of policy implementation. To increase political will and commitment, policy frameworks focusing on environmental and social considerations that sponsor and encourage co-operation between government entities are needed.

Consensus-making with diverse stakeholders

Renewable energy projects often involve diverse stakeholders, including local communities, Indigenous peoples, environmental groups and industry players. Building consensus among these groups can be challenging due to different priorities and varying levels of influence. Failing to reach a consensus can lead to project delays, increased costs or even cancellations.

Engaging stakeholders early in a meaningful way helps prevent conflicts and fosters community support, reducing project risks and costs associated with delays. Quality of engagement is defined by many factors, of which most notably is a dialogue format that is based on mutual trust and consideration. There is a need for dedicated resources and training for developers and governments to effectively conduct stakeholder engagement and mapping, participatory planning processes, and conflict resolution strategy.

Cost factors

Implementing environmental best practices can incur additional costs related to planning, technology, monitoring and enforcement. Emerging markets and developing economies may face financial limitations, restricted access to technology and a shortage of skilled professionals for these practices, while in developed markets these factors are often already sufficiently priced into business cases.

Although expenses related to environmental best practice might be initially higher in developing markets, investing in this area can lead to long-term savings by avoiding environmental harm, legal liabilities, community resistance and reputational damage. Sustainable projects are also more likely to attract foreign investment and public support.

Complexity and fragmentation of existing policies

Policies related to environmental protection and renewable energy regulation are often complex and fragmented across various government agencies and levels, especially when frameworks do not account for the technological specificities of different technologies, such as for offshore wind. This fragmentation or unalignment can lead to confusion, regulatory overlaps or gaps, hindering the effective integration of environmental considerations into project planning and execution.

Simplifying and harmonising policies can reduce administrative burdens, expedite project approvals and improve compliance rates, resulting in cost savings for governments and developers. While this requires often increased initial training and capacity building, in the long term this investment generally results in improved market development.

Limited capacity for effective implementation

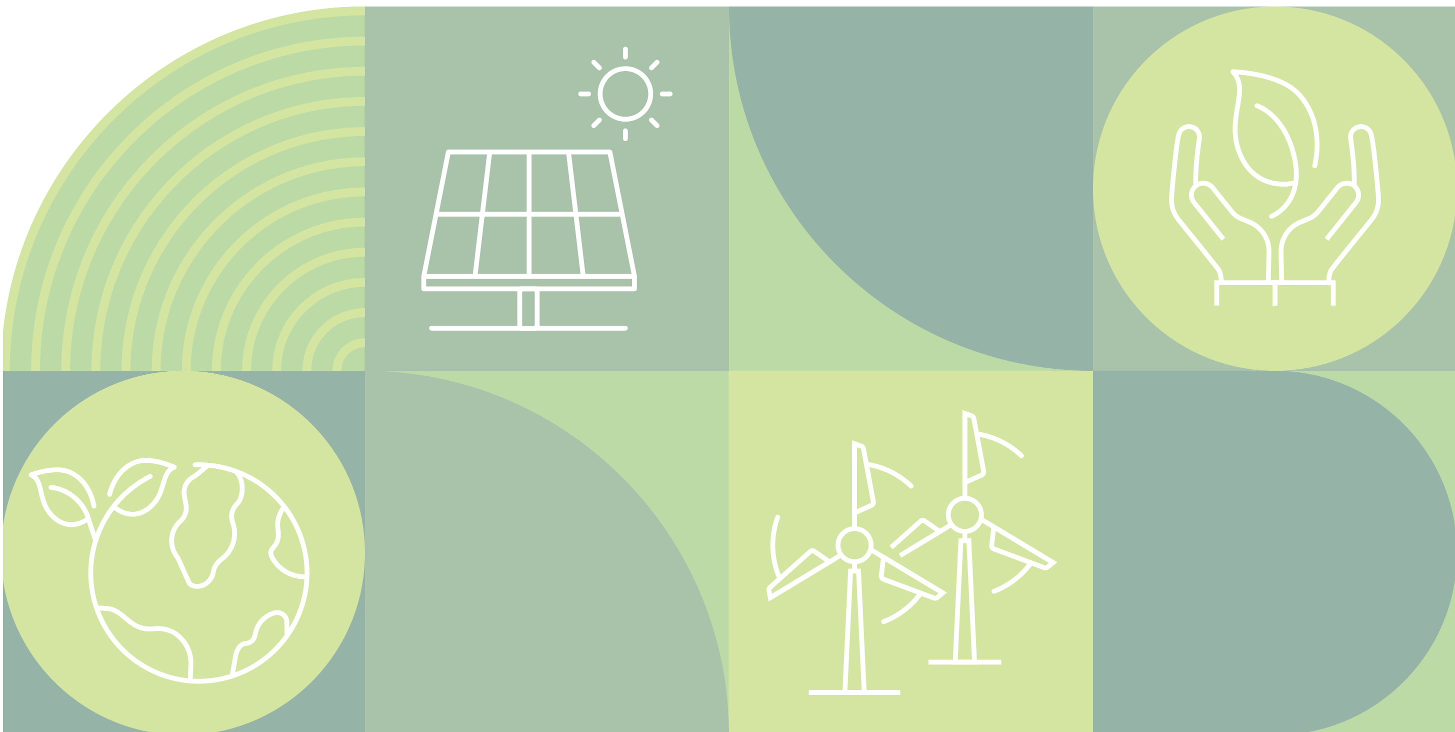
Even with strong policies and best practices, practical implementation remains a significant challenge. Issues include limited institutional capacity, technical expertise and enforcement mechanisms. Lack of transparency can further obstruct effective implementation.

Strengthening implementation and enforcement ensures that environmental goals are met, reducing the risk of environmental degradation and associated costs. Effective implementation also enhances public trust and project legitimacy and signals reliability to financial lenders, thus improving trust in project feasibility and reducing financial risks. This might require institutional capacity-building and training programmes for regulators, as well as budgets for additional personnel.

Creating a level playing field

Ecosystem costs and benefits are challenging to estimate and are often underrepresented in economic evaluations of renewable energy projects. Without accounting for environmental externalities, projects may appear more economically viable than they are, leading to decisions that undervalue ecosystem services and biodiversity.

Incorporating environmental and related social costs and benefits provides a more accurate assessment of project viability and encourages investment in genuinely sustainable projects. This approach also helps avoid future costs related to environmental restoration and loss of ecosystem services. Therefore, the development and adoption of methodologies for valuing ecosystem services is needed, as well as training for economists and planners, and policy instruments that focus on internalising environmental costs (*e.g.* taxes, subsidies or payment schemes for ecosystem services).



05 Recommendations

Enabling frameworks and supportive conditions are needed to remove barriers and ensure the effective application of principles in accelerating renewable energy and grid infrastructure deployment. The policy recommendations are detailed below.

Integrated, cross-sectoral approach

1. **An integrated approach is required that aligns energy development plans and Nationally Determined Contributions (NDCs) with international targets on climate, biodiversity and sustainable land management at regional, national and sub national levels.** Nature, energy and climate perspectives are interdependent in terms of achieving Sustainable Development Goals and emissions reductions, and halting biodiversity loss and land degradation. As such, stronger involvement and collaboration of energy and environment stakeholders is needed, including public authorities, private sector and civil society organisations. Integrated energy planning should take into consideration the impacts of the whole value chain, from raw material demand, siting and permitting, to decommissioning and the end-of-life management of renewable technologies.

2. **Cross-sectoral collaboration should be enabled at the earliest stage of renewable energy planning** to ensure the intended targets are met in a feasible, cost-effective way and preventing avoidable damage to the environment and biodiversity. Co-ordination should be improved between the energy department and other departments related to environment, land-use planning and agriculture. Regulators and energy developers should involve conservation organisations and experts to assess nature sensitivity, and define and implement monitoring plans and mitigation and restoration measures. Teamwork based on the involvement of energy engineers, biodiversity experts and local actors across the whole life cycle of renewable projects has been proven to deliver positive outcomes. Policies and solutions must be tailored to local context and maximise the benefits to local communities.

3. **Financing and policy tools should be aligned to mainstream nature-positive energy development.** Renewable energy investors and developers need to integrate the assessment of biodiversity, and social and environmental risks at the earliest stage into renewable energy planning and investment decisions. Financial institutions and international development banks should align investment criteria with the Convention on Biological Diversity. These criteria can be included in bidding processes and energy auctions. Companies sourcing renewable energy can include biodiversity considerations in the procurement policies. It is important to improve corporate disclosure and reporting on biodiversity, as well as environmental and social impacts.

Strengthening capacity, integrating scientific and local knowledge

4. **It is important to scale up the use of technological innovations combined with data, and both scientific and local knowledge to enable robust environmental management.** Technological innovations, digital tools and platforms enhanced with AI applications are increasingly used and should be further scaled up and made accessible to all stakeholders to manage environmental outcomes. These include interactive maps showing nature-sensitive areas, technologies for monitoring and adaptive management to avoid possible impacts to local species, and forecasting, such as the migration patterns of birds. Nature-sensitivity mapping can help policy makers and project developers identify possible interaction aspects, and the level of impact renewable energy systems and associated grid infrastructure may bring to the environment and the ecosystem. Such tools must be adapted to a local context and based on proper data input, requiring continuous collaboration with specialised organisations and local stakeholders.

5. **Engaging communities and utilising local knowledge are essential to ensure responsible siting and permitting processes.** This requires collaboration with local stakeholders, giving voice to those with less power, especially indigenous groups, local communities, women and youth. Nature-positive energy solutions are context-specific and can be successful in the long term only with meaningful participation and buy-in of local communities. Integration of ecosystem restoration measures presents tangible benefits for local communities, building stronger public acceptance and legitimacy. Transparency and accountability build trust and positive interaction between communities and projects. Energy developers should involve and work with local communities, conservation organisations, biodiversity experts and policy makers to identify nature and heritage sites and harness co-benefits.

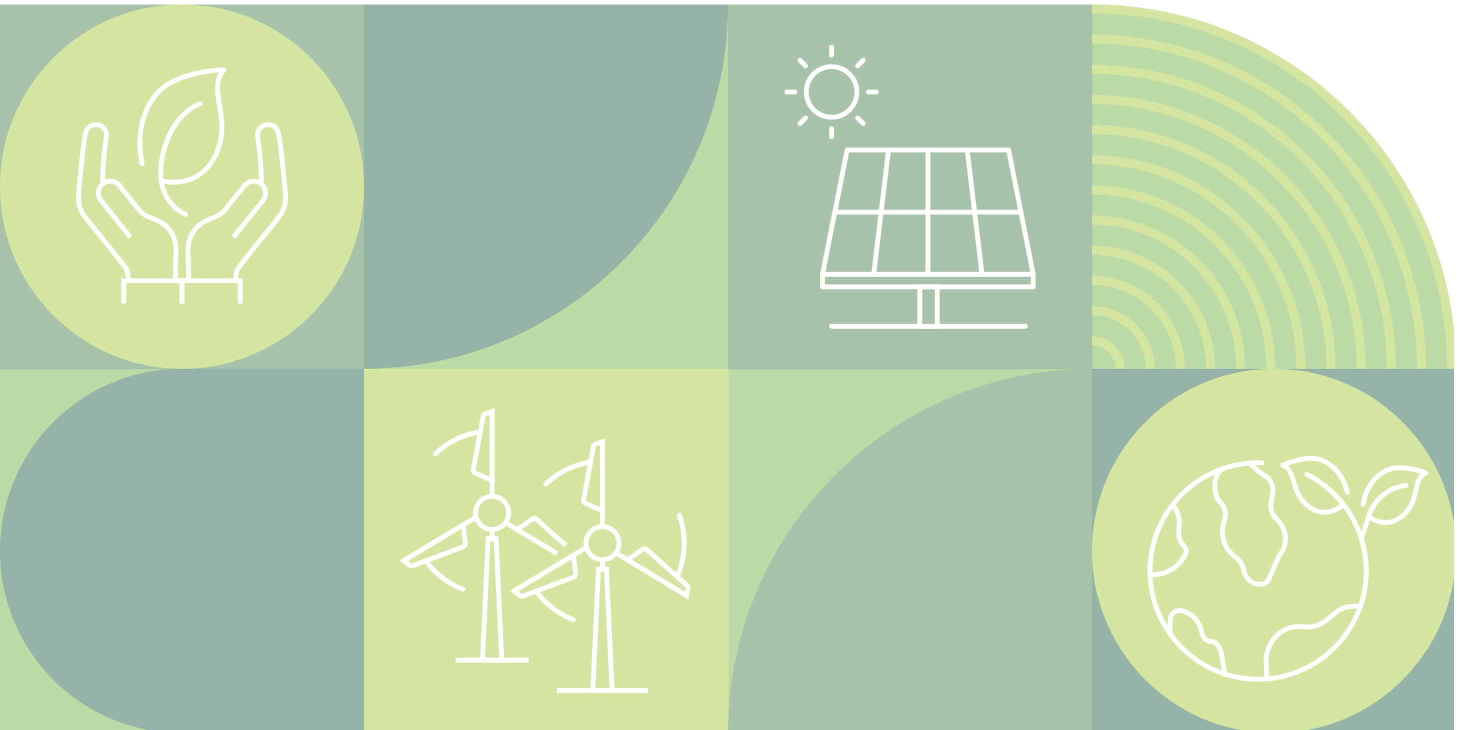
6. **Further research is required to fully understand the value of biodiversity and improved ecosystems for renewable energy projects and local communities.** This would provide considerable strength for energy and environmental departments to further incentivise sustainable siting and permitting practices. It is also important to enhance awareness of benefits of healthy ecosystems and their services among private sector and civil society. Joint efforts, such as public campaigns and capacity building to policy makers, energy and biodiversity stakeholders are necessary to better understand links of biodiversity and renewable energy infrastructure, as well as existing technologies, approaches and solutions for mutually beneficial strategies.

Streamlining processes

7. **Governments should define priority areas to enable an efficient permitting process that accelerates renewable energy roll-out without compromising the environmental aspects.** National-level strategic environmental assessments should complement project-level assessments, anticipating areas where environmental impacts are minimal, or synergies can be achieved for dual use. Such streamlined approach can fast-track renewable energy siting and permitting processes.

8. **A one-stop-shop approach can streamline siting and permitting processes by providing clear guidance for developers.** There is a need to enhance standardisation to reach more accurate and accountable decisions in the siting and permitting procedures. It is important to apply effective biodiversity safeguards and environmental impact mitigating procedures to avoid and minimise impacts, as well as offset any residual impacts to achieve net-positive outcomes. Some biodiversity topics, such as migratory species or interconnected biodiversity habitats, methodologies, data collection, and regulations, should be consistent and harmonised at regional or cross-regional levels.

9. **Practical tools based on the principles outlined in this paper are necessary to guide all related stakeholders in the roll-out of renewable energy.** Building on existing research, a toolbox for policy makers, financing institutions and renewable energy developers should be developed to enable implementation measures. These measures adjusted to local conditions and inputs should guide the successful acceleration of renewable energy uptake while halting and reversing biodiversity loss.



References

Bennun, L. *et al*. (2021), "Mitigating biodiversity impacts associated with solar and wind energy development: guidelines for project developers", IUCN, International Union for Conservation of Nature, https://doi.org/10.2305/iucn.ch.2021.04.en.

Bennun, L. *et al*. (2024), "Guidance on biodiversity cumulative impact assessment for wind and solar developments and associated infrastructure", IUCN, International Union for Conservation of Nature, Gland, https://doi.org/10.2305/ehge6100.

Berros, M. V. (2021), "Challenges for the implementation of the rights of nature: Ecuador and Bolivia as the first instances of an expanding movement", *Latin American Perspectives*, vol. 48/3, pp. 192–205, SAGE Publications, https://doi.org/10.1177/0094582x211004898.

Biasotto, L. D., *et al*. (2022), "Routing power lines: Towards an environmental and engineering friendly framework for avoiding impacts and conflicts in the planning phase", *SSRN Electronic Journal*, Elsevier BV, https://doi.org/10.2139/ssrn.4052424.

Biodiversity Company (2023), *The terrestrial biodiversity baseline & impact assessment for the mainstream Stilfontein grid project*, Biodiversity Company, Johannesburg, https://sahris.sahra.org.za/sites/default/files/additionaldocs/10AppD2_Terrestrial%20Ecology%20Report_10_MTS.pdf.

CBD (2024), "Kunming-Montreal Global Biodiversity Framework", Secretariat of the Convention on Biological Diversity, www.cbd.int/gbf (accessed 18 February 2025).

Copping, J. P., *et al*. (2025), "Solar farm management influences breeding bird responses in an arable-dominated landscape", *Bird Study*, pp. 1–6, Informa UK Limited, https://doi.org/10.1080/00063657.2025.2450392.

Ecology by Design (2022), "Biodiversity mitigation hierarchy explained", *Ecology by Design*, www.ecologybydesign.co.uk/ecology-resources/biodiversity-mitigation-hierarchy (accessed 18 April 2025).

Economic Times (2023), "Hyderabad's new solar-covered cycle track illuminates the city and people's wallets", https://economictimes.indiatimes.com/news/india/hyderabads-new-solar-covered-cycle-track-illuminates-the-city-and-peoples-wallets/articleshow/104101218.cms?from=mdr (accessed 27 January 2025).

Ellen MacArthur Foundation (2021), *The Nature Imperative: How the Circular Economy Tackles Biodiversity Loss*, Ellen MacArthur Foundation, Cowes, www.ellenmacarthurfoundation.org/biodiversity-report.

Enel (2023), *Sustainability Report 2023*, www.enel.com/content/dam/enel-com/documenti/investitori/sostenibilita/2023/sustainability-report_2023.pdf.

Energy Environmental Economics (2024), *Assessment of Renewable Energy Siting and Permitting Policies*,

European Commission (2025), "The EU Nature Restoration Law", https://environment.ec.europa.eu/topics/nature-and-biodiversity/nature-restoration-law_en (accessed 19 February 2025).

European Parliament (2022), "Renewable Energy, Energy Performance of Buildings and Energy Efficiency Directives: Amendments (REPowerEU)", www.europarl.europa.eu/doceo/document/TA-9-2022-0441_EN.pdf.

European Parliament (2023), "Directive (EU) 2023/2413 of the European Parliament and of the Council", https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023L2413&qid=1699364355105.

European Parliament (2024), "Energy efficiency of buildings: MEPs adopt plans to decarbonise the sector", www.europarl.europa.eu/news/en/press-room/20240308IPR19003/energy-efficiency-of-buildings-meps-adopt-plans-to-decarbonise-the-sector (accessed 22 January 2025).

Government of Canada (2021), "Consolidated federal laws of Canada, United Nations Declaration on the Rights of Indigenous Peoples Act", https://laws-lois.justice.gc.ca/eng/acts/u-2.2/FullText.html (accessed 28 January 2025).

Government of India (2024), "National Portal for PM-KUSUM", https://pmkusum.mnre.gov.in/#/landing (accessed 17 March 2025).

Government of India (2025), "PM Surya Ghar: Muft Bijli Yojana", https://pmsuryaghar.gov.in/#/ (accessed 17 March 2025).

Government of South Australia (2021), "Premier's Awards 2021", *Energy & Mining*, www.energymining.sa.gov.au/industry/geological-survey/mesa-journal/previous_news/news-articles-2021/premiers-awards-2021 (accessed 17 March 2025).

Invernizzi, D. C., *et al*. (2020), "Developing policies for the end-of-life of energy infrastructure: Coming to terms with the challenges of decommissioning", *Energy Policy*, vol. 144, pp. 111677, Elsevier BV, https://doi.org/10.1016/j.enpol.2020.111677.

IPCC (2020), "Energy is at the heart of the solution to the climate challenge", www.ipcc.ch/2020/07/31/energy-climatechallenge (accessed 27 January 2025).

IRENA (2024), *World Energy Transitions Outlook 2024: 1.5°C Pathway*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/-/media/Files/IRENA/Agency/Publication/2024/Nov/IRENA_World_energy_transitions_outlook_2024.pdf.

IRENA, *et al*. (2024), *Delivering on the UAE Consensus: Tracking progress toward tripling renewable energy capacity and doubling energy efficiency by 2030*, International Renewable Energy Agency, COP28 Presidency, COP29 Presidency, Global Renewables Alliance, Ministry of Energy of the Republic of Azerbaijan, Government of Brazil, Abu Dhabi, www.irena.org/Publications/2024/Oct/UAE-Consensus-2030-tripling-renewables-doubling-efficiency.

IRENA (2025), *Renewable capacity statistics 2025*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2025/Mar/Renewable-capacity-statistics-2025.

IRENA (n.d.), "SolarCity Simulator", www.irena.org/Energy-Transition/Project-Facilitation/Renewable-potential-assessment/SolarCity-Simulator (accessed 20 February 2025).

IRENA Coalition for Action (2024), *Community energy benefits: Powering universal wellbeing*, International Renewable Energy Agency, Abu Dhabi, https://coalition.irena.org/-/media/Files/IRENA/Coalition-for-Action/Publication/IRENA_Coalition_Community_energy_benefits_wellbeing_2024.pdf.

IRENA Coalition for Action (forthcoming, 2025a), *Greener pastures: Success stories of renewable energy transforming agriculture and livelihoods*, International Renewable Energy Agency, Abu Dhabi, www.irena.org.

IRENA Coalition for Action (forthcoming), *REPowering for tripling: Advancing wind energy*, International Renewable Energy Agency, Abu Dhabi, www.irena.org.

IUCN (2024), *Spatial Planning for Wind and Solar Developments and Associated Infrastructure*, International Union for Conservation of Nature, Gland, https://portals.iucn.org/library/node/52091.

Joshi, S., *et al*. (2021), "High resolution global spatiotemporal assessment of rooftop solar photovoltaics potential for renewable electricity generation", *Nature communications*, vol. 12/1, pp. 5738–5738, England, https://doi.org/10.1038/s41467-021-25720-2.

JRC (2023), "Agrivoltaics alone could surpass EU photovoltaic 2030 goals", https://joint-research-centre.ec.europa.eu/jrc-news-and-updates/agrivoltaics-alone-could-surpass-eu-photovoltaic-2030-goals-2023-10-12_en (accessed 27 January 2025).

Kakani, M., *et al.* (2024), "The restoration launchpad: A step-by-step guide for restoration planners and practitioners", *World Resources Institute*, World Resources Institute, https://doi.org/10.46830/wrigb.21.00045.

Kiesecker, J. M., *et al*. (2024), "Land use and Europe's renewable energy transition: identifying low-conflict areas for wind and solar development", *Frontiers in Environmental Science*, vol. 12, Frontiers Media SA, https://doi.org/10.3389/fenvs.2024.1355508.

Lamnatou, C., and Chemisana, D. (2015), "A critical analysis of factors affecting photovoltaic-green roof performance", *Renewable and Sustainable Energy Reviews*, vol. 43, pp. 264–80, Elsevier BV, https://doi.org/10.1016/j.rser.2014.11.048.

Legifrance (2023), "LOI n° 2023-175 du 10 mars 2023 relative à l'accélération de la production d'énergies renouvelables (1)", 2023-175, www.legifrance.gouv.fr/jorf/id/JORFTEXT000047294244 (accessed 27 January 2025).

Masdar (2024), "Masdar harnesses power of AI to protect birds of prey at Zarafshan wind farm", https://masdar.ae/en/news/newsroom/masdar-harnesses-power-of-ai-to-protect-birds-of-prey-at-zarafshan-wind-farm (accessed 14 April 2025).

McCall, J., *et al*. (2023), "Vegetation management cost and maintenance implications of different ground covers at utility-scale solar sites", *Sustainability*, vol. 15/7, pp. 5895, MDPI AG, https://doi.org/10.3390/su15075895.

Nature Conservancy (2020), "Six pathways to a clean and green energy buildout", *The Nature Conservancy*, www.nature.org/en-us/what-we-do/our-insights/perspectives/clean-green-renewable-energy-buildout (accessed 29 January 2025).

Nature Conservancy (2021), "Our clean energy future is not just about 'how'—it's also 'where'", *The Nature Conservancy*, www.nature.org/en-us/what-we-do/our-insights/perspectives/our-clean-energy-future-is-not-just-about-how-its-also-where (accessed 29 January 2025).

Nature Conservancy (2025), "The Nature Conservancy announces 17 new clean energy projects on former Appalachian coal mines with ENGIE and Sun Tribe Development", *The Nature Conservancy*, www.nature.org/en-us/newsroom/cumberland-clean-energy-former-mines (accessed 28 April 2025).

Nature Positive Initiative (2025), "What is Nature Positive?", www.naturepositive.org/, www.naturepositive.org/what-is-nature-positive (accessed 24 February 2025).

Ravi, S., *et al*. (2016), "Colocation opportunities for large solar infrastructures and agriculture in drylands", *Applied Energy*, vol. 165, pp. 383–92, Elsevier BV, https://doi.org/10.1016/j.apenergy.2015.12.078

REN21 (2023), *Renewable Energy and Sustainability Report*, www.ren21.net/wp-content/uploads/2019/05/REN21-RESR-2023_LowRes.pdf (accessed 1 February 2024).

REN21 (2024), *Renewable Energy and Sustainability Report*, REN21, Paris, www.ren21.net/renewable-energy-and-sustainability-report-2024.

Renewable Energy Magazine (2024), "ScottishPower restores more than 1,000 hectares of wetlands at Whitelee Wind Farm", www.renewableenergymagazine.com/wind/scottishpower-restores-more-than-1-000-hectares-20240923? (accessed 4 November 2025).

RGI (2024), *RGI Statement on Renewables Acceleration Areas*, Renewables Grid Initiative, Berlin, https://renewables-grid.eu/fileadmin/user_upload/Files_RGI/RGI_Publications/Position_Papers/RGI_statement_on_the_renewables_acceleration_areas-2.pdf.

Ruiten, K., *et al*. (2023), "Drawing the line: Opening up and closing down the siting of a high voltage transmission route in the Netherlands", *Land Use Policy*, vol. 132, pp. 106804, Elsevier BV, https://doi.org/10.1016/j.landusepol.2023.106804.

ScottishPower Renewables (2025), "Whitelee Windfarm", ScottishPower Renewables, www.whiteleewindfarm.co.uk/pages/whitelee_windfarm_about_us.aspx (accessed 28 January 2025).

Sercy, K., and Cavert, J. (2024), "Siting, leasing, and permitting of clean energy infrastructure in the United States", Niskanen Center – Improving Policy, Advancing Moderation, www.niskanencenter.org/siting-leasing-and-permitting-of-clean-energy-infrastructure-in-the-united-states (accessed 27 January 2025).

SierraLii (2022), "Mines and Minerals Development Act", https://sierralii.gov.sl/akn/sl/act/2023/16/eng@2023-05-12 (accessed 28 January 2025).

Spiess, T., and De Sousa, C. (2016), "Barriers to renewable energy development on brownfields", *Journal of Environmental Policy & Planning*, vol. 18/4, pp. 507–34, Informa UK Limited, https://doi.org/10.1080/1523908x.2016.1146986.

Tian, J., *et al*. (2024), "Is renewable energy sustainable? Potential relationships between renewable energy production and the Sustainable Development Goals", *npj Climate Action*, vol. 3/1, Springer Science and Business Media LLC, https://doi.org/10.1038/s44168-024-00120-6.

UN (2022), "Causes and effects of climate change", United Nations, United Nations, www.un.org/en/climatechange/causes-and-effects-climate-change?utm_source=chatgpt.com (accessed 30 January 2025).

UNFCCC (2022), "What is the triple planetary crisis?", https://unfccc.int/news/what-is-the-triple-planetary-crisis (accessed 27 January 2025).

US Environmental Protection Agency (2015), "What is RE-Powering", *Overviews and Factsheets*, www.epa.gov/re-powering/what-re-powering (accessed 17 October 2023).

WEF (2023), "3 unusual ways renewable energy is giving farming a boost", *World Economic Forum*, www.weforum.org/stories/2023/10/agriculture-farmers-renewable-energy (accessed 27 January 2025).

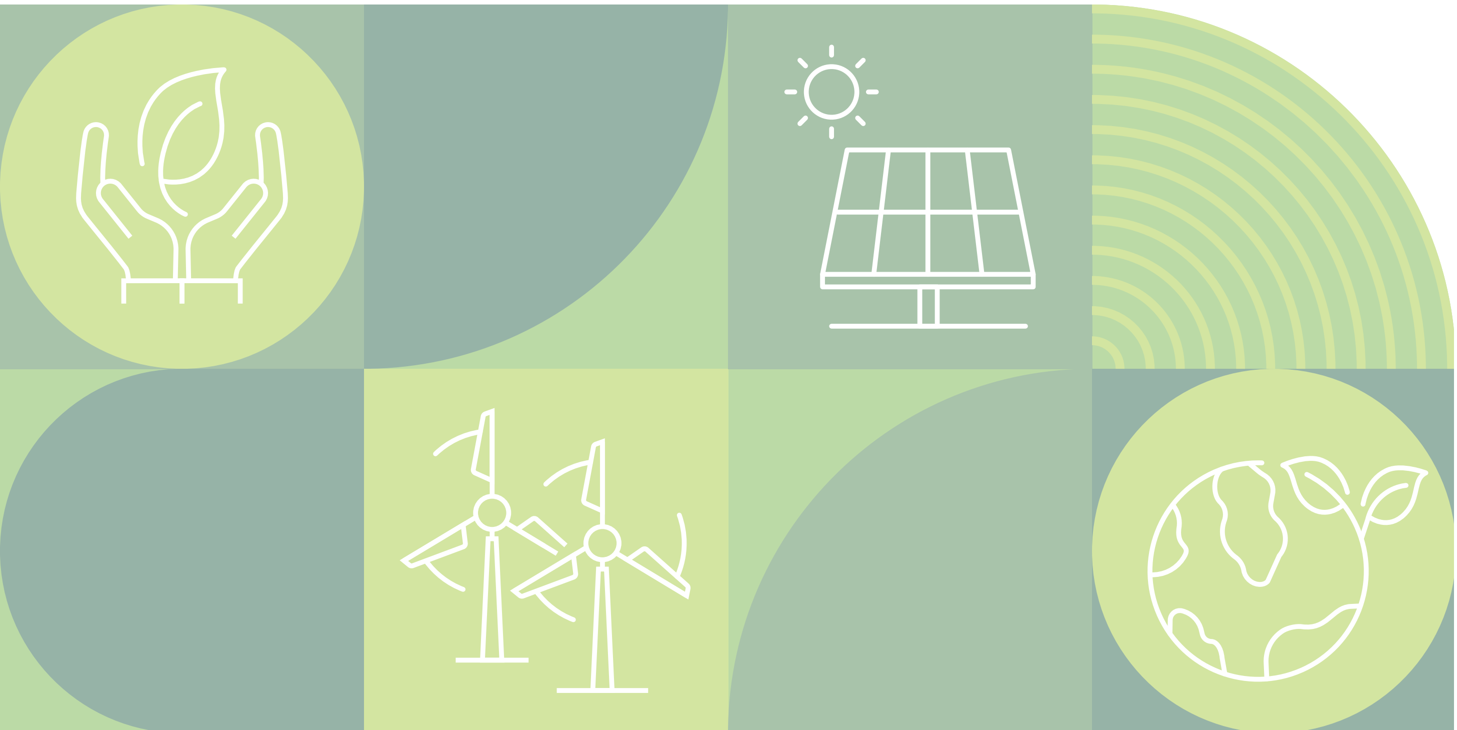
WEF (2025), "Principles for responsible deployment of renewable energy infrastructure", *World Economic Forum*, https://reports.weforum.org/docs/WEF_Principles_for_Responsible_Renewables_Deployment_2025.pdf

WRI (n.d.), "Responsible Energy Initiative", www.wri.org/initiatives/responsible-energy-initiative (accessed 9 April 2025).

WWF (2024), Living Planet Report 2024 – *A System in Peril*, WWF, Gland, https://files.worldwildlife.org/wwfcmsprod/files/Publication/file/5gc2qerb1v_2024_living_planet_report_a_system_in_peril.pdf

WWF, CAN Europe, The Nature Conservancy, Birdlife International, EEB (2024), "European Commission guidance on Renewables Acceleration Areas", https://wwfeu.awsassets.panda.org/downloads/joint-ngo-letter-on-guidance-for-renewable-acceleration-areas.pdf.

Yin, J., *et al*. (2025), "The impacts of power transmission and transformation projects on ecological corridors and landscape connectivity: a case study of Shandong province, China", *Scientific Reports*, vol. 15/1, pp. 6709–6709, England, https://doi.org/10.1038/s41598-025-91474-2.



ANNEX 1 Stakeholders, their motivations and interactions

Stakeholder	Roles	Motivations	Interactions	Power to act
International and regional organisations	Facilitator, Funder, Convenor	Promote climate change mitigation through deployment of renewable energy technologies	Central governments, Non-Governmental Organisations (NGOs), Private sector	**Voluntary –** Define narratives and principles Inform policy-making Financial, technical and capacity-building support
Central government	Funder, Facilitator, Convenor	Promote renewable energy deployment Achieve emissions mitigation Strategic direction Plan infrastructure Ensure energy access Create economic opportunities	Local governments and authorities, Developers, utilities, grid operators Industry, associations, NGOs, Regulators, Planning agencies, Developers, Investors	**Statutory –** Policy-making, creating enabling environment Create mandates, incentives and penalties Define protected areas
Local governments and authorities	Convenor, Planner, Funder, Facilitator, Enforcer, Integrator	Legal requirements and generating political will or interest in the energy transition Ensuring energy access and reliability and affordability	Developers (incl. housing organisations and energy communities), Residents, Planning agencies, Local communities and Indigenous people, NGOs	**Statutory –** *(depending on the country/ political context)*, Can act as a project developer/ support projects development Can act as a convener among stakeholders and link to regional and national authorities Public procurement of electricity
National Regulatory Authorities (NRAs)	Regulator, Enforcer	Ensuring compliance with defined processes and defining new processes, Set prices and market mechanisms	Central government, Local government, Local communities, NGOs, Developers, Prosumers	**Statutory –** Conduct public consultations and hear various stakeholders Enforce regulations and monitor compliance

Stakeholder	Roles	Motivations	Interactions	Power to act
Planning agencies including Transmission System Operators (TSOs) and Distribution System Operators (DSOs) utilities	Planner, Integrator	Ensure connectivity of energy supply and grid stability	Energy planners (national/ regional) National and local authorities/ developers	Statutory
Developers	Planner, Implementor, Convenor	Deployment and operation of renewable energy plant Maintenance of assets Sale of electricity Generate returns	Central government, Local government and authorities Investors, Planning agencies, Producers/ suppliers / installers/ contractors (PSIC), Industry associations, Local communities and indigenous people	**Statutory –** Planning generation and evacuation infrastructure, generation scheduling Voluntary - Local participation and unlock community benefits
Investors	Funder	Promote renewable energy deployment Generate returns Diversify risks	Developers PSICs	**Voluntary –** Performance of project, monitor developer practices
PSICs (Producers/ suppliers / installers/ contractors)	Implementor	Provide renewable energy products and components for deployment	Developers	**Voluntary –** meeting service requirements
Industry associations	Facilitator, Convenor	Advocate for preferential policies, incentives, *etc*. For renewable energy deployment	Central and local governments	**Voluntary –** advocacy for policies and incentives
Local communities and indigenous people, local stakeholders (*e.g*. local businesses, fishermen, farmers, tourism sector)	Facilitator, co-developer, impacted party	Gaining influence on the process/end result Community gains (monetary and non-monetary benefits) Secure livelihoods	Developers / TSOs or DSOs Local governments Environmental Non-Governmental Organisations (ENGOs)	Statutory and voluntary (depending on the country/ political system)

Stakeholder	Roles	Motivations	Interactions	Power to act
Prosumers	Co-developer	Electricity access and reliability, income generation	Utilities	Statutory and voluntary (depending on the country/ political system)
Environmental state authorities	Regulator, Convenor, Facilitator, Planner	Protect environment and ecology	Local communities and indigenous people NGOs National and local governments	**Statutory –** require environmental clearance, monitoring
NGOs	Convenor, Facilitator, Planner Advocate	Representing interests related to the public, impacted communities and nature protection	Local governments Communities Developers/ TSOs or DSOs	**Voluntary –** Inform international and regional organisations, policy makers, regulators and authorities Inform national and local policies Protect community interests and ecology Educate prosumers, industry associations, developers

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