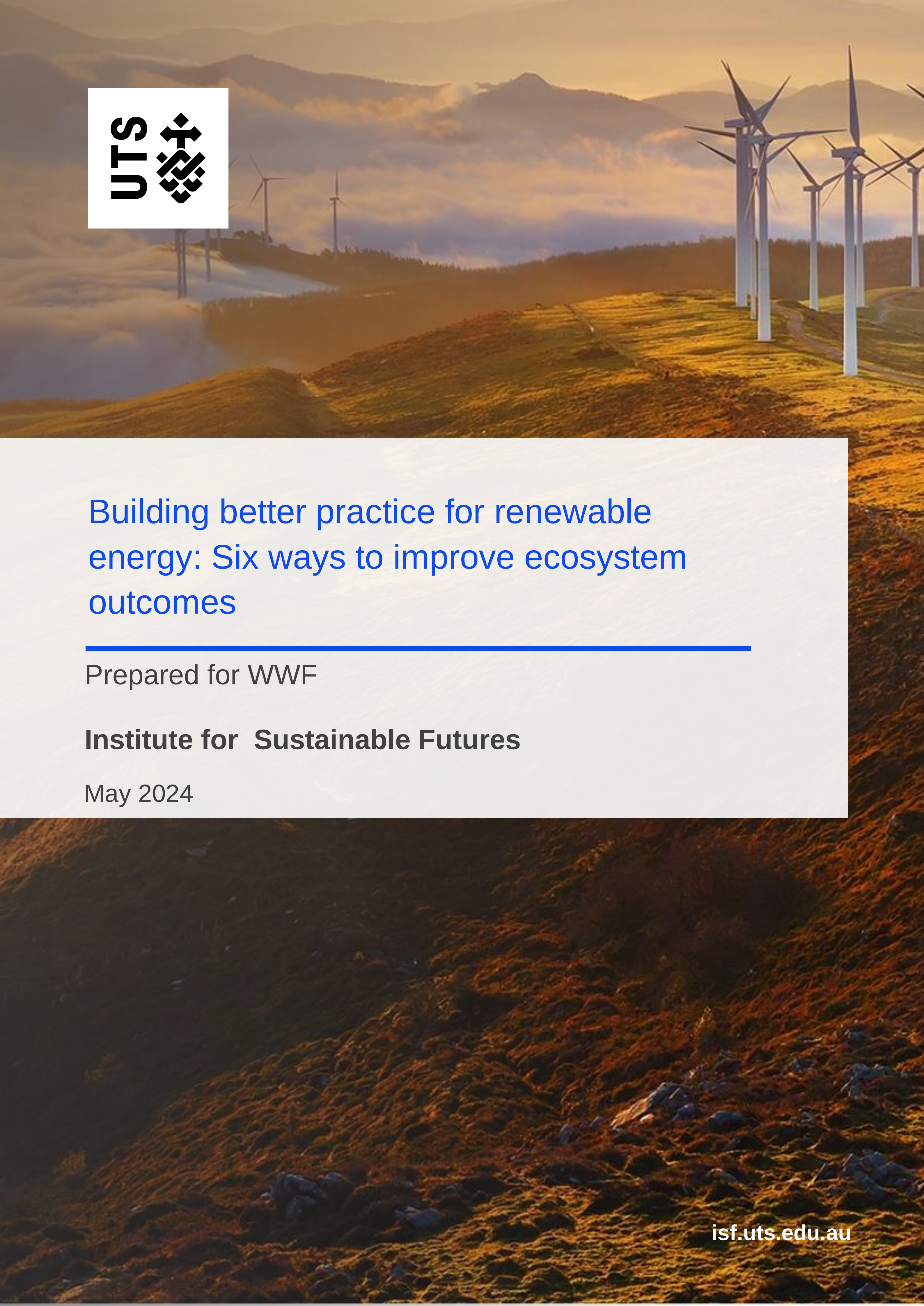

Building better practice for renewable energy: Six ways to improve ecosystem outcomes

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The Institute for Sustainable Futures (ISF) is an interdisciplinary research and consulting organisation at the University of Technology Sydney. ISF has been setting global benchmarks since 1997 in helping governments, organisations, businesses and communities achieve change towards sustainable futures. We utilize a unique combination of skills and perspectives to offer long term sustainable solutions that protect and enhance the environment, human wellbeing and social equity.

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Introduction

The world is confronted with two inter-twined environmental crises: climate change and biodiversity loss. Climate change is damaging ecosystems by modifying temperatures, rainfall and increasing the occurrence and intensity of extreme weather events (IPCC, 2022). Simultaneously, the biodiversity crisis is fuelled by a range of other threats, including habitat loss due to agricultural and urban development, resource extraction, invasive species, and pollution. Seventy-five per cent of the world's land surface has been significantly impacted by human activities (IPBES, 2019) and global wildlife populations fell by 69 per cent on average between 1970 and 2018 (WWF, 2022). Australia has the highest number of mammal extinctions in the world and numerous species continue to decline (WWF, 2022). The deterioration of ecosystems and their biodiversity is, in turn, accelerated by climate change. There is no solution to the biodiversity crisis without rapid emissions reductions to address climate change.

One of the core pathways to net zero greenhouse gas emissions is a dramatic scaling up of renewable energy to transition from fossil fuels to a clean power system. According to the IEA (2021) – International Energy Agency - renewable energy will grow from 20 per cent of electricity generation in 2020 to 90 per cent by 2050 under a net zero pathway. In Australia, the Federal Government has set a target of 82 per cent renewable energy by 2030, aligned with the 'Step Change' scenario in the Australian Energy Market Operator's Draft 2024 Integrated System Plan (AEMO, 2023). The Minister for Climate Change and Energy, Chris Bowen, estimates that achieving this 2030 target will require installing 40 large wind turbines every month and 60 million solar panels (Bowen, 2022).

Renewable energy has lower impacts on human and environmental health (i.e. ecotoxicity, eutrophication and acidification) than fossil fuel generation (Luderer et al., 2019; UNEP, 2016). A recent study by WWF & BCG (2023) comparing a business-as-usual scenario and a rapid transition scenario[1] found that the latter would lead to a smaller mining footprint, a reduction in water pollution as well as lower risk for biodiversity, natural habitats, and ecosystems. In spite of this, the scale and speed at which renewable energy will need to be deployed to address climate change carries significant risks for ecosystems. Renewable energy deployment at this scale (notably for solar farms and bioenergy) will, for example, have significant land requirements (Luderer et al., 2019) and large volumes of critical minerals such as lithium, cobalt and nickel will be required to make renewable energy technologies and electric vehicles (Dominish et al., 2019).

As more renewable energy projects are rolled out, a passionate debate is building within and across local communities about the impacts of renewable energy on ecosystems. There are legitimate concerns about the environmental impacts of mining for lithium and other critical minerals, the loss of agricultural land, landscape and habitat impacts during the development and construction of large-scale wind and solar farms, bird and bat strikes during the operation of wind farms and the generation of waste from renewable energy technologies.

The good news is that there are a range of options available to mitigate these risks. Strategic planning can avoid biodiversity hotspots. Circular economy practices can reduce mineral demand (Simas et al., 2022). Careful site design can ensure wildlife corridors remain connected and revegetation can contribute to habitat and species regeneration. The use of new sensory technologies can reduce bird and bat strike by wind turbines.

However, in practice, striking the balance between a rapid transition to clean energy and ecosystem protection will be extremely challenging. Whilst there is a body of studies evaluating various environmental impacts of renewable energy technologies, the evidence is unfortunately often not definitive on either the magnitude of impacts or the efficacy of mitigating initiatives. For example, many but not all studies find the impacts of carefully sited wind farms on birds and bats are modest, but the body of longitudinal before-and-after studies one would like to have full confidence does not exist. There are smart technology options emerging for switching turbines off as birds and bats are detected approaching, but whilst results are promising it is still relatively early days to evaluate their effectiveness.

A good-faith approach to reconciling the development of renewable energy and ecosystem protection involves recognising a thorny problem: a rapid scale-up in renewable energy is required to address climate change, but there will be trade-offs which often minimise rather than eliminate environmental impacts. We will need to 'build it as we go' because we do not have the luxury of time to fully evaluate impacts and solutions. The data, systems, practices,

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[1] The business-as-usual scenario assumes that countries pursue their current climate policies, which is likely to lead to a rise of 3.2 C by the end of the 21st century. The rapid transition scenario limits the temperature rise to 1.5 C through adoption of renewable energy, electrification, and energy efficiency. In this scenario, renewable represent 85% of global primary energy supplies by 2050 – solar energy is the main renewable energy source, followed by bioenergy, onshore wind, hydro, offshore wind and geothermal.

and technologies to minimise biodiversity impacts are going to have to be developed in parallel with the roll-out of renewable energy. An honest, collaborative approach is therefore required between governments, industry, environmentalists, and First Nations communities, involving open dialogue, knowledge sharing, better regulation, and policy to drive iterative changes towards best (or better) practices.

Our report aims to make a contribution towards the development of a collaborative approach by providing the latest information on 'better' practice and an overview of studies on renewable energy and ecosystems. After outlining global best practice principles for renewable energy and biodiversity (the 'Mitigation and Conservation Hierarchy'), we identify six ways in which renewable energy can improve its ecosystem outcomes and case studies that illustrate them in practice.

In the Appendix I to the report, there is a wider literature review from which the key challenges and case studies have been extracted. The literature review contains a summary of the latest studies on the impacts across the life cycle (raw material sourcing, processing, and manufacturing; construction and installation; operation; decommissioning and disposal) on three ecosystem dimensions (habitat and wildlife, water, and soil) and mitigation options. Based on stakeholder interviews, Appendices II, III, IV, V and VI provide further insights on the drivers, factors of success and challenges of various projects aiming to address the ecosystem related impacts of renewable energy.

In many cases, the information available on the environmental impacts of renewable energy technologies is uneven, qualitative and lacks the robust evidence to make definitive statements. We present the information knowing that different readers may find aspects to disagree with. It is therefore simply meant as a resource which can provide a picture of available information – even if it will not end the debates. The intended audiences for this report are renewable energy proponents, governments, environmental organisations, and individuals interested in proactively reducing the impacts of renewable energy. We hope that this report will provide them with a better understanding of the ecological impacts and relevant information on the types of measures that can be taken to mitigate the impacts of renewable energy projects. Further research is necessary to better assess the environmental impacts of renewable energy technologies in Australia and elsewhere.

The large-scale deployment of renewable energy is a complex phenomenon at the crossroad of technology, environment, and society. While the focus of this report is on the interactions between renewable energy and biodiversity, we acknowledge that there are other related impacts which are beyond the scope of this report but important to consider:

- The development of renewable energy, notably solar and bioenergy, may compete with land used for food and forest production (Dias et al., 2019; Fritsche et al., 2010). Such frictions are already evident in Australia where solar farms sometimes overlap with productive agricultural land (Taylor, 2021). The trade-offs and synergies between land use for renewable energy generation and food production need to be considered.

- The influence and involvement of First Nations communities in renewable energy projects need to be increased to ensure that First Nations peoples benefit from the energy and that renewable energy does not become the latest wave of colonisation (Chandrashekeran, 2021; Norman & Briggs, 2022).

- As mentioned earlier, the climate and biodiversity crises are interwoven, each of them impacting and worsening the effects of the other. In this report we specifically focus on the impacts of renewable energy on ecosystems. However, we do not explore the impacts on ecosystems of remaining fossil fuel dependent. This is done in a recent WWF & BCG (2023) which, compares the environmental impacts of remaining in a fossil fuel dependent model versus ramping up the use of renewable energy.

While these dimensions are beyond the scope of our report, it is important they be addressed if the deployment of renewable energy in Australia is to be environmentally sound and socially just.

The Mitigation and Conservation Hierarchy

The Mitigation Hierarchy developed by the International Finance corporation presents a set of principles that aim to counterbalance the environmental impacts of infrastructure development to reach a no-net-loss[2] of biodiversity, meaning that actions are undertaken to neutralise the negative environmental impacts of a project. The hierarchy is composed of four steps that must be used sequentially: avoidance, minimisation, restoration/rehabilitation and offsets (see Table 1).

More recently, the Mitigation and Conservation Hierarchy (MCH) has been developed by a coalition of academics, NGOs and private organisations, to establish a framework that goes beyond 'no-net-loss' of biodiversity and aims to achieve 'nature-positive' outcomes (Milner-Gulland et al., 2021). In addition to mitigating the direct impacts of infrastructure projects, the MCH sets out principles for proactive conservation measures that address 'historical, systemic and non-attributable' biodiversity loss across the same four steps (Conservation Hierarchy, 2022; Sinclair et al., 2020). The aim of a nature-positive approach is to:

> "*halt and reverse nature loss measured from a baseline of 2020, through increasing the health, abundance, diversity and resilience of species, populations and ecosystems so that by 2030 nature is visibly and measurably on the path of recovery*" (Nature Positive, n.d.)

While reaching nature positive outcomes is now a priority for infrastructure developments, only few examples have been implemented worldwide (FIDIC et al., 2023). This is also true for renewable energy infrastructure. As a result, current better practices for renewable energy infrastructure appear to mainly follow the mitigation pathway. However, the renewable energy sector should be looking to the MCH as best practice and should thrive to apply both the mitigation and conservation pathways.

Table 1: The Mitigation and Conservation Hierarchy

	Mitigation Pathway	**Conservation Pathway**
Refrain	Measures to prevent adverse impacts on biodiversity. e.g: siting a project in an area that avoids biodiversity hotspots and prioritises degraded land (e.g. industrialland).	Measures to proactively protect biodiversity hotspots and important sites. e.g: the establishment and management of protected areas.
Reduce	Measures to reduce the intensity, significance, duration and/or extent of impacts that cannot be avoided. e.g: physical barriers during construction to limit thefootprint of the project and minimise impacts on ecosystems.	Proactive measures to protect ecosystemsand habitat during all project phases.
Restore	Measures to repair impacts on biodiversity and ecosystems (e.g. habitat restoration) that cannot becompletely avoided. e.g: Replanting native trees, shrubs and grasses that were temporarily impacted during construction.	Measures taken to actively restore degradedhabitats in and around sites. e.g: Restoring sites degraded by humanactivities beyond the project.
Renew	Measures to conserve and improve ecosystems in other areas to compensate for the adverse impacts of a project that cannot be avoided, minimised and/or restored through measures earlier in the hierarchy e.g: Offsetting residual impacts by undertaking conservation actions that compensate for the biodiversity loss caused by the development.	Measures taken to proactively create new ecosystems e.g: The creation of new ecosystems, through urban green projects for example.

Sources: Conservation Hierarchy, 2022; Milner-Gulland et al., 2021; Sinclair et al., 2020; The Biodiversity Consultancy, n.d.

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[2] It is important to note that 'no-net-loss' only exists in comparison to a baseline. If the baseline adopted is based on current trends of decline, then projects using the mitigation hierarchy may contribute to further biodiversity declines.

Better practice for renewable energy: six ways to improve ecosystem outcomes

Based on a literature review, we have identified six types of improvements that can contribute to reconciling the global development of renewable energy and ecosystem protection:

1. **Implementing strategic planning to minimise habitat loss**: Avoiding sites with a high-risk of habitat and biodiversity loss is the most powerful way of reducing the environmental impacts of renewable energy development (CLEANaction, 2023; RE Alliance & The Energy Charter, 2023). It is harder (if not impossible) to mitigate impacts at later stages of projects. The first-best solution is strategic planning at a regional scale, informed by experts, industry, and local communities, to map and identify appropriate locations. Two case studies presented below provide examples of guidelines and maps developed to inform developers on siting that will minimise impacts on biodiversity. The Renewable Energy Zones in Australia provide a platform for more strategic planning. The University of Melbourne is currently identifying lower risk areas where the deployment of renewable energy will have the lowest possible impact on biodiversity and agriculture, as well as areas that should be off limits (Biodiversity Council, 2024). However, if and how this mapping exercise will interact with the Renewable Energy Zones remains unclear.

2. **Improving site selection to minimise land-use impacts and designing projects for 'nature positive' outcomes**: There are opportunities through site selection and design for individual projects to minimise land-use changes and biodiversity impacts – and to even improve biodiversity ('nature-positive' outcomes). Some of the approaches used include locating projects on degraded land, siting infrastructure to avoid sensitive habitat and maintain wildlife corridors and revegetating and restoring habitats.

3. **Increasing the uptake of circular economy practices to minimise materials, water use and waste:** Circular economy practices can minimise the environmental impacts of renewable energy, by reducing resource use and extending the lifecycle of products (e.g. wind turbines). A circular economy framework could be established for the Renewable Energy Zones (REZs) where most of the large-scale development will occur in Australia, to drive better practices across the renewable energy sector.

4. **Using smart operating technologies and multi-functional land-use to minimise impacts during operation**: There is potential for impacts on fauna to be reduced with smart technology. For example, AI technology is now emerging and being used at wind farms to stop turbines when they detect the presence of birds they have been trained to identify. In the case of solar energy, the co-location of solar farms with agriculture may represent a more efficient use of the land, that would allow for both energy generation and food production concurrently. Smarter technologies and multi-functional land uses need to be diffused through innovation, knowledge sharing and regulation.

5. **Minimising waste and land impacts at end-of-life and decommissioning of renewable energy technologies**: Materials that end up in landfill can pollute and represent a missed opportunity to reuse and recycle and, this way, reduce the mining of virgin materials which have high impacts on the environment. End-of-life management can avoid materials ending up in landfill, through reuse or recycling. Innovation is required to extend recycling processes to problem waste streams (e.g. turbine blades) and regulation and policy to increase reuse and create end-markets for recycled product. Trials such as the New South Wales *Circular Solar Trial* (developing a novel solar panel recycling process and activating end-markets for recovered solar panel glass) need to be expanded.

6. **Reducing impacts from mining and manufacturing in renewable energy supply chains:** Scaling up renewable energy will lead to an expansion in manufacturing and mining of critical minerals (Dominish et al., 2019) – with the potential for large impacts on societies and the environment where mining occurs. The major renewable energy technologies (i.e. solar, wind, battery) require mining and processing of critical minerals which are water and energy-intensive and use toxic chemicals which, if not managed, can pollute soils, water, and ecosystems. Taking the example of batteries, the extraction, processing, and manufacturing of battery minerals currently has widespread impacts on water, soil, habitats, and wildlife, largely because the mining governance regimes of countries with abundant reserves of critical minerals often fail to meet international sustainability standards (Future Battery Industries CRC, 2020). New regulatory approaches (e.g. the European Union Battery Regulation) and certification systems (the Initiative for Responsible Mining Assurance) offer model for driving improvements.

For each of the six areas, we summarise why those improvements are important, some of the existing and emerging approaches, and case studies. Some of the cases presented are best-practice, others are more accurately called ‘better practice’. If renewable energy is to be reconciled more effectively with biodiversity, we need regulation, initiatives, and programs to diffuse and scale up best (and better) practice.

1. Implementing Strategic Planning to minimise habitat and biodiversity loss

Why is it important?

The widespread roll-out of some renewable energy, such as large-scale solar farms, are likely to have a high land footprint, which could have impacts on agricultural land and encroach into fragile ecosystems (Gibbens, 2022; Taylor, 2021). Wind farms can also encroach on biodiversity hotspots or be sited in areas where they impact on birds and bats (Gasparatos et al., 2017; UNEP, 2016). Avoiding sites with high ecological value is crucial to reduce the impacts of renewable energy development on habitat and biodiversity.

Existing and emerging approaches

The best approach is strategic planning and siting at a regional scale, informed by experts, industry, and local communities. A range of existing tools have been used to support strategic planning:

- Regional conservation plans can be developed by policy makers to guide project proponents (Bennun et al., 2021; Stoms et al., 2013).
- Biodiversity sensitivity maps can be developed to assist with identifying sites to avoid biodiversity hotspots (Bennun et al., 2021; Moore-O’Leary et al., 2017; Stoms et al., 2013).
- Data-analysis tools can be used to facilitate decision-making such as land suitability analysis and multicriteria analysis (Stoms et al., 2013). Key datasets include land-use or land-cover maps, protected areas (e.g., national parks, wilderness areas), tree-cover/forest maps, native vegetation maps, sighting data of threatened flora and fauna species and ecosystems, bird migration maps, wetlands maps and heritage sites (Stoms et al., 2013). Site-specific biological data collected from field surveys needs to be incorporated into the analysis. CLEANaction (2023) provide details on a range of existing tools to support strategic planning in different parts of the world.

Strategic planning can facilitate and accelerate development by supporting social license and avoiding project-by-project disputes. The Renewable Energy Zones provide a platform for the development of a strategic planning approach to biodiversity across key regions.

Case studies

Case study: Nebraska Wind and Wildlife Working Group: High level strategic planning through mapping and guidelines

In the U.S., the state of Nebraska has one of the greatest potentials for wind energy due to its availability of open land, with 2.2 million hectares or 11% of the region defined as low-impact suitable land, equating to 66–110 GW capacity (Hise et al., 2022). Conversely, there is strong opposition to wind farm developments in Nebraska.

The Nebraska Wind and Wildlife Working Group Guidelines (the Guidelines) aim to standardise negotiation processes between project developers and the relevant government agencies (The Nebraska Wind and Wildlife Working Group, 2016). The Guidelines complement existing processes including the coordination and consultation with the state and federal agencies such as the Nebraska Game and Parks Commission (NGPC) and the U.S. Fish and Wildlife Service (USFWS).

The Map

The Map was developed from spatial layers with various indicators associated with threatened species, landscapes, wetlands, and waterways. It aims to support and facilitate decision-making among stakeholders on land-use and locations/designs of wind farms, and the development of mitigation measures (e.g., buffer distances from wind turbine and infrastructure) and costs. The Map can accurately demonstrate the relative sensitivity of wildlife habitats to wind projects, and the best location for projects to mitigate impacts (The Nebraska Wind and Wildlife Working Group, 2016). The three levels of sensitivity on the map are:

- Minimum Mitigation Areas – lower concentration of sensitive species and fauna, lower impacts to wildlife, mitigation recommended for some sites including forests, wetland, and grasslands

- Moderate Mitigation Areas – higher impacts on site than for minimum mitigation areas

- Maximum Mitigation Areas – avoiding development is recommended, high sensitivity very vulnerable sites, mitigation will not compensate the impacts to the site

Best practice is to develop wind energy projects in 'Minimum Mitigation Areas'. The data suggests that, by doing this, there will be fewer impacts on wildlife and biodiversity overall compared with developing projects in other areas. As it is unlikely that any mitigation measures would adequately compensate for the impacts to biodiversity in 'Maximum Mitigation Areas', avoiding development in these areas is recommended (The Nebraska Wind and Wildlife Working Group, 2016b; University of Nebraska-Lincoln, n.d., 2016).

The Guidelines

Accompanying the Map are the 'Guidelines for Avoiding, Minimizing, and Mitigating Impacts of Wind Energy on Biodiversity in Nebraska' (the Guidelines) (The Nebraska Wind and Wildlife Working Group, 2016). The Guidelines have made various improvements on the previous development guidelines. This includes development of the Map, pre- and post-construction guidelines, and mitigation guidelines for wind energy developers and operators. The previous development guidelines and assessment processes were limited to the site's condition and impact during the pre-construction phase. The updated Guidelines acknowledge the importance of assessing the long-term (more than five years post-construction) effects of wind farms on biodiversity, as well as cumulative impacts. The Nebraska Wind and Wildlife Working Group (2016) recommends site assessments including bird/plant surveys at both pre- and post-construction phases. As uncertainty remains on these impacts, future research efforts are also suggested in the Guidelines.

Case study: The Nature Conservancy

This type of approach can also be used for solar energy. For example, The Nature Conservancy (TNC), in the U.S., has conducted a spatial analysis to identify key wildlife areas that should be avoided by solar and wind developers in the Central part of the country: Site Renewables Right (The Nature Conservancy, 2022). TNC encourages solar developers to use the mapping tool that resulted from this analysis, to identify sites that are preferable – from a wildlife and habitat standpoint – for the development of solar projects. TNC is also conducting a more thorough analysis called 'Power of Place' that identifies areas that should be excluded for development due to biodiversity values and determines the amount of energy that can be supplied by the remaining land under various scenarios (The Nature Conservancy, 2023).

2. Improving site selection to minimise land-use impacts and project design for 'nature-positive' outcomes

Why is it important?

The construction of renewable energy infrastructure can lead to a range of ecosystem related impacts:

- The construction of solar farms involves a range of activities (e.g., vegetation removal, land grading, addition of gravel, use of heavy machinery, use of dust suppressants and herbicides) that can lead to soil erosion and compaction, reduced water quality, habitat destruction and wildlife displacement (Hernandez, Hoffacker, et al., 2014; Lovich & Ennen, 2011; Macknick et al., 2014; Nordberg et al, 2021; Tawalbeh et al, 2021; Turney & Fthenakis, 2011).
- The physical footprint of wind power infrastructure can lead to habitat and wildlife loss, habitat fragmentation, displacement, and degradation (Bennun et al., 2021; Dai et al., 2015; Hastik et al., 2015).
- Hydropower substantially alters water flow, nutrient cycles and sediment loading, along with the movement of aquatic species (Gasparatos et al., 2017; UNEP, 2016; Van Den Berg et al., 2001; Zhang et al., 2022).

Site selection and design can avoid or reduce the impacts of those infrastructures on ecosystems.

Existing and emerging approaches

Site selection

There are opportunities to install renewable energy on **degraded landscapes** to reduce ecosystem impacts (CLEANaction, 2023):

- *Solar farm examples:* Over-grazed livestock properties, landfills, industrial land, spent mines or contaminated sites can be used for solar farms (Hernandez, Easter, et al., 2014; Macknick et al., 2014; Moore-O'Leary et al., 2017; Nordberg et al., 2021; Tawalbeh et al., 2021). When located in degraded landscapes, solar farms could even provide habitat benefits by adding structures such as shelters, nesting and perching sites and protection from prey species (Nordberg et al., 2021; Wu et al., 2022).
- *Hydropower examples*: Hydropower infrastructures can be built in existing or artificial reservoirs, such as old mining sites (Blakers et al., 2021). A recent example is the 250MW Kidston Pumped Storage Hydro Project in Far-North Queensland, which is being constructed in an old goldmine (Louloudis et al., 2022; Richards, 2022).

However, it is important to remember that to address the biodiversity crisis restoring ecosystems is necessary in addition to protection and conservation. The UN *Decade on Restoration*, which started in 2021, highlights the importance of "prevent[ing], halt[ing] and revers[ing] the degradation of ecosystems on every continent and in every ocean" (UN Environment Programme, n.d.). As such, striking the right balance between the use of degraded land for renewable energy deployment and ecosystem restoration should remain a consideration.

Project design

Project design strategies can be put in place to protect habitat, vegetation, and the wildlife they shelter:

- *Solar power examples***:** Panels and other infrastructure (e.g. roads, cables etc.) can be placed to: i) avoid encroaching on and fragmenting habitat, ii) maintain a buffer between infrastructure and areas of importance and iii) enable the passage of wildlife through the site (e.g. maintaining vegetation strips or wildlife corridors using wildlife-friendly fencing (Bennun et al., 2021; Guerin, 2017; Nordberg et al., 2021; Sinha et al., 2018). In addition, measures can be taken to improve habitat and enhance vegetation, such as adding new vegetation to the site (e.g. planting vegetation between panels or around the site), along with habitat features (e.g. nest boxes) (Macknick et al., 2014; Nordberg et al., 2021; Sinha et al., 2018).
- *Wind power example*: Avoidance zones can be created around ecologically sensitive areas and wildlife corridors can be provided to limit the risk of collisions (Bennun et al., 2021).
- *Hydropower example*: Several design and construction measures can be harnessed to reduce the impacts of hydropower infrastructure on migratory fish species. Gateways, such as fish ladders, can be used to facilitate fish to access to upstream waterways in storage hydropower (Wollebæk et al., 2011). Upstream and downstream movements of fish species can also be enabled in run-of-river plants using natural bypass channels, rock ramps or engineered structures (Anderson et al., 2015; NSW Government Department of Primary Industries, n.d.).

Case studies

Case study: Bomen Solar Farm

Bomen Solar Farm is a 120MW project developed near Wagga Wagga, developed by Renew Estate and Spark Infrastructure. The project was underwritten through corporate renewable purchase agreements, notably with Westpac and the City of Sydney. Westpac was a foundational buyer and both the buyer and developer parties worked to develop a project with high environmental and social value.

There are a number of notable features of the Bomen Solar Farm for a biodiversity and agriculture perspective. Bomen Solar farm is sited on 250 hectares of land zoned industrial, which included wool manufacturing. The use of a brownfield site avoids habitat destruction and the NSW Department of Planning and Environment had already undertaken a biodiversity assessment of the industrial park site, which reduced time and costs. One of the conditions of the agreement with Westpac was the exploration of multi-use options for the site. Ground cover was selected to support sheep grazing and regeneration of the local bee population. Sheep grazing from neighbouring farmers enables them to feed their livestock and reduces the costs of grass management for fire safety by the solar developers (see section 4 for further information on Agrivoltaics). There were public objections to the visual impacts of the solar farm which were addressed by landscaping, vegetation screens. Additionally, biodiversity enhancement efforts were made through the planting of 50,000 trees.

See Appendix II for further details on the drivers of change, factors of success and challenges in developing the project

Case study: Better Energy

Better Energy (BE) is a Danish renewable energy company. The measures undertaken by BE primarily relate to the avoid and reduce steps of the mitigation hierarchy and the restore step of the conservation hierarchy.

During the site selection phase, BE prioritises land that is considered as having ‘low nature value’, primarily agricultural land. At the planning phase, biodiversity assessment of the site and surrounding landscapes are conducted by internal and/or external biodiversity and environmental experts to provide information on the possibilities, options, and challenges that the site represents in terms of biodiversity. Consultation is organised with local communities, where additional insights on local biodiversity can be gathered that may not be available in the scientific literature. These initial assessment and consultation processes inform BE on how they should protect existing biodiversity when developing the site and what could be done to enhance it further.

During the design phase of the project, the main considerations are to locate panels at a distance from existing natural areas within and beyond the site and avoid areas that are enabling wildlife movement (e.g. wildlife corridors). To enhance biodiversity, the on-site measures that are often considered include:

- mechanically removing nutrient rich topsoil to expose the nutrient-poor sandy soils and facilitate the development of grassland areas (this technique is costly and has so far been piloted on small areas to measure its effectiveness).
- creating new habitats, such as hedgerows and windbreaks that can provide shelter and food for wildlife and water bodies that can benefit amphibians.
- planting native grasses under panels to enable grazing – activities that can be conducted underpanels are limited by the height of the panels and the shade they provide.
- restoring wetland by installing solar panels on drained lowland areas and stopping drainage.

During construction, practices which can have negative impacts such as leveling the ground are avoided when possible and small and light machinery is utilised. Native grasses are planted before construction to minimise the damage done by machinery and workers on soil.

During operation, native grasses under the panel are grazed rather than controlled with herbicide. Regular reviews of the site are conducted, which enable BE to assess the outcomes of the measures taken and to make adjustments in order to improve them.

<u>Challenges:</u>

The implementation of biodiversity related measures can be challenging for several reasons. Firstly, restoring biodiversity on agricultural land where little biodiversity remains can sometimes be difficult, and potentially promising measures (e.g., topsoil removal) can be costly. Secondly, the costs of integrating biodiversity into solar projects is included in the overall costs of a project and viability depends on the project margins and other cost drivers (e.g. size of the site, grid connection etc.).

<u>Future developments:</u>

One of BE’s major priorities is to allocate larger pieces of land to biodiversity within projects. A past project – Blangslev – allowed for the development of micro-habitats distributed across the site. BE is now developing a project where a larger proportion of the site (one third) is dedicated to biodiversity conservation and enhancement.

See Appendix III for further details on the drivers of change, factors of success and challenges in developing the project.

Case study: The Nature Conservancy (North Carolina)

The North Carolina chapter of The Nature Conservancy (TNC) provides guidance on the design of solar facilities, primarily focusing on the reduce step (mitigation) and restoration step (conservation):

-Adapting conservation measures to the context: Solar developers are encouraged to think about the 'matrix' they are in and to design measures that are relevant to that specific context. For example, if a development is located in a forested ecosystem with a large number of animals, they should consider using wildlife friendly fencing. If the site is in an agricultural matrix, the focus may be on planting vegetation that attracts pollinators complementing adjoining agricultural land.

- **Providing wildlife-friendly fencing or wildlife corridors**: Fencing with large holes enables animals to pass through the fence whereas corridors leave unfenced passageways in the site to facilitate the movement of larger animals.

- **Protecting habitat features and planting pollinator vegetation**: Protecting existing habitat features on the site (e.g. wetlands or riparian areas) provides habitat refuges and help animals move through a site.

Challenges

The main challenge faced by the TNC is to encourage the adoption and uptake of their guidelines, which are voluntary. One way to facilitate uptake by solar developers is to raise awareness around issues relating to wildlife and solar installations. While this has been achieved in parts of the U.S. where 'iconic' mammals migrate, it has been harder in North Carolina where those iconic species do not tend to occur. While some habitat and wildlife friendly practices may be costlier and require additional management, others do not require large amount of time and financial investments (i.e. wildlife friendly fencing). Those practices can be used as a first step to engage developers in thinking about wildlife and habitat outcomes on their site.

Future developments:

Options were identified to facilitate the adoption and enhance the effectiveness of wildlife and habitat friendly practices on solar developments. Firstly, developers who implement conservation practices on their sites could be rated as more conservation friendly. Secondly, comprehensive quantitative research needs to be conducted on the benefits of wildlife friendly practices, so as to identify the most effective practices and improve them. Finally, as solar facilities multiply across the landscape, it is becoming increasingly important to look at the landscape scale impacts in order to implement measures to limit landscape fragmentation.

See Appendix IV for further details on the drivers of change, factors of success and challenges in developing the project.

Case study: Lightrock Power

Lightrock Power (LP) is a solar farm developer based in the United Kingdom. The actions and measures undertaken by LP primarily relate to the avoid and reduce steps of the mitigation hierarchy and the restore step of the conservation hierarchy.

During the site selection phase, environmental designations present in the UK (e.g. Green Belt or Special Scientific Interest) means that many projects are conducted on degraded agricultural land rather than on land with high biodiversity value.

At the project planning phase, initial surveys are conducted to establish a baseline of the ecology of the site, identify species at risk of being disturbed by the project, along with opportunities to create additional habitat. This phase of the project is conducted in collaboration with environmental organisations (e.g., Royal Society for the Protection of Birds) who conduct site visits and provide recommendations.

The data generated during this phase informs the design of the project. While each project has different specificities and needs, some of the measures adopted in most projects relate to:

-enhancing existing habitat, such as 'gapping up' discontinuous hedgerow so that they constitute an effective wildlife corridor.

- adding floristic diversity by sowing wildflower mixes in the field margin to attract certain species (e.g. dormice, which in turn make food for raptors).

- enabling grazing under panels by sowing grasses and native wildflower; and

- providing additional habitat features such as boxes for birds and bats.

During construction, an environmental management plan is developed that includes measures aiming to reduce impacts on habitat, notably fencing off water bodies and hedgerows.

During operation, employees are made aware of the ecological features of the site during toolbox talks. They may therefore provide ‘ad hoc’ observations, such as species sighting. Additionally, ecologists monitor sites periodically, which provides learnings to improve practices in other projects.

Challenges:

The development of solar projects that integrate biodiversity considerations may slow down the design phase of a project as gathering the ecological data to establish a baseline for a site may take a year or more considering that surveys need to be conducted at specific times of the year.

Biodiversity initiatives can have – real or perceived – financial implications, as they may require a reduction in the amount of energy produced and require additional steps to be taken at the design stage. However, such projects can also lead to reduced management costs (e.g. using grazing may be cheaper than hiring contractors to spray the grass under the panels).

Future developments:

Further areas of investigation for LP relate to accreditations and adopting a landscape approach. The ‘Fair to Nature’ program run by the Royal Society for the Protection of Birds accredits farmers who manager their farm responsibly. LP is looking into the possibility to translate this accreditation to their solar development business. They also increasingly recognise the importance of considering their projects as a ‘node in a network’ and to ensure that their projects are sited in areas that contribute to broader landscape conservation. This brings us back to the importance of strategic planning.

See Appendix V for further details on the drivers of change, factors of success and challenges in developing the project.

Case study: Genex Power

Genex Power is an Australian owned company focused on developing renewable energy and storage projects. Its flagship project is the Kidston Clean Energy Hub in Lyndhurst, Queensland. Once completed, the Kidston Clean Energy Hub will encompass a 50MW solar project (stage 1), a 270MW solar project (stage 2), 258MW wind project, and a 250MW pumped hydro energy storage (PHES) system (Genex Power, n.d.).

The Kidston PHES system will be capable of storing up to 8 hours of energy. Water will be cycled from a lower reservoir to an upper reservoir through pipes and tunnels (International Hydropower Association, n.d.). During periods of surplus energy, when demand is low, water will be pumped from the lower reservoir to the upper reservoir. When demand is high, the water will be released through a turbine to generate electricity (Florin & Dominish, 2017). The Kidston project is being developed on an abandoned gold mine. Siting projects on abandoned or degraded land like the Kidston PHES, can avoid the worst impacts on biodiversity and ecosystems. The construction and operation of the Kidston PHES will provide valuable insights into the effectiveness of PHES systems in Australia, such as development issues, construction costs and timelines, operational logistics and the Australian regulatory environment for PHES systems (ARENA, n.d.).

3. Increasing the uptake of circular economy practices

Why is it important?

Renewable energy projects require significant resources during the construction and operation phases (e.g. water) and use energy-intensive materials (e.g. critical minerals) that have environmental impacts at the mining, processing, and manufacturing phases.

Existing and emerging practices

Opportunities exist to reduce resource use and increase resource recovery on sites, but there appears to have been less focus here than on other impacts of renewable energy infrastructures. The examples provided below primarily look at ways to reduce resource use during construction. One of our case studies (Siemens Gamesa) provides an example related to reducing material use during operation by extending the lifespan of wind turbines.

Solar power example: water use for the cleaning and cooling of panels can be reduced by:

- Reducing the intensity of site grading and housing the cables above ground rather than in ground trenches to reduce dust emissions, which, in turn, will reduce the amount of water needed to clean the panels (Sinha et al., 2018).
- Orienting the panels to enable 'self-cleaning', which limits the need to use water (Guerin, 2020).
- Implementing water retention and recuperation infrastructures on site (Oudes & Stremke, 2021).

Wind power example: NatureScot - Scotland's nature agency has developed guidelines to better manage construction waste for wind farms (NatureScot, 2019).The guidelines include the following:

- Reusing excavated rock materials to improve roads and levees.
- Where woodland removal is necessary, selling any merchantable timber, leaving tree stumps and roots in place to avoid soil destabilisation and run-off into waterways, and using any residual tree materials (e.g., mulch) to support habitat restoration.
- Implementing sustainable drainage practices, such as collecting and treating water run-off and wastewater.

Green hydrogen example: Recycled water from wastewater treatment plants (WWTPs) could be used during operation (Freund et al., 2020). Pilot projects using purified water from WWTPs to create hydrogen are being trialled by water utilities in NSW and Victoria (Barwon Water, 2022; Harris, 2021; Water Research Australia, 2021). Australia's first commercial hydrogen re-fuelling station - under development in Geelong, Victoria - will use recycled water from Barwon Water's Northern Water Plant (Viva Energy, 2022).

The integration of circular economy principles in the construction and operation of renewable energy infrastructures is another area that would benefit from strategic planning. A circular economy framework could be established for the REZs, encompassing innovation, infrastructure, skills, and engagement to drive better practice across the renewable energy sector.

Case Studies

Case study: Midelt Wind Farm

Located in Draa-Tafilalet, Morocco, the Midelt Wind Farm, developed by Enel Green Power (EGP), Moroccan Agency for Sustainable Energy, Nareva Holding and Platinum Power (Power Technology, 2024) incorporated sustainable construction practices in the construction phase of the project lifecycle. The 210 MW windfarm is part of Morocco's Integrated Wind Farm program. The aim of the program is to build a wind farm network with a combined 850 MW (Enel Green Power, 2018). The actions implemented at the Midelt Wind Farm focused primarily on the reduce step of the mitigation hierarchy. Some of the practices adopted were (Enel Green Power, 2019, 2021, 2023):

- Using excavation materials to upgrade levees and roads,
- Reusing wood pallets as signs on the site,
- Developing a waste recycling system for metal, pallets, and lubricants,
- Reusing greywater and wastewater used to manufacture concrete and wash vehicles.

Enel Green Power has developed a Sustainable Construction Site model to formalise the sustainable practices used in their projects. This model is replicated on sites across the world. For example, the Cohuna Solar Farm (operational) and the Girgarre Solar Farm (under construction) (Victoria, Australia) followed the Sustainable Construction Site Model (Enel Green Power, n.d.-a, n.d.-b).

Siemens Gamesa: Extending the Lifespan of Turbines

Siemens Gamesa has introduced a life extension program to extend the life of older turbines through monitoring and structural upgrades (Siemens Gamesa, n.d.). Condition monitoring service systems use sensors to detect anomalies and vibrations, identifying and carrying out corrective actions early. The average lifespan of a wind turbine is estimated to be 20 years. The life extension program can increase the operating life for up to 10 years (Siemens Gamesa, 2022).

Extending the operating lifespan can provide financial benefits (relative to de-commissioning and building new turbines) and reduce the resource use of the industry.

4. Using smart operating technologies and multi-functional land-use to minimise impacts during operation

Why is it important?

Wind farm example: Around the world, concerns about the operation of wind farms relate to the risk of collision by birds and bats, either due to blade strike or barotrauma (Gasparatos et al., 2017; Peste et al., 2015; UNEP, 2016). While bird strike by wind turbines is a source of much controversy, there is unfortunately a limited body of peer reviewed studies looking at avian species mortality before and after the implementation of wind power infrastructure. A study conducted in Victoria from 2003 to 2018 estimates that there is a rate of between 0.1 and 6.2 bird deaths per turbine, per year of operation, for the species covered in the study (Moloney et al., 2019).

Solar farm example: The deployment of utility-scale solar farms is going to requires large amounts of land (Luderer et al, 2019), which means that land-use competition is likely to occur between renewable energy generation, food production and ecosystem conservation (Gibbens, 2022; Taylor, 2021).

Current and emerging approaches

Impacts on fauna and flora can be reduced (directly or indirectly) during the operation of renewable energy technologies.

Wind farm example: As mentioned above, impacts of wind turbines on avian species have been an area of particular concern. A range of options have been developed to reduce the risk of collision with birds:

- Electromagnetic fields, acoustics and visual deterrents can be used to redirect wildlife away from wind farms (Gartman et al., 2016). For example, a study conducted in Norway demonstrated that painting the turbine blades black to increase visibility reduced annual fatality rates by 70%, particularly for raptors like the white-tailed eagle (May et al., 2020). However, it should be noted that there is a risk of eventual habituation and reduced effectiveness of these measures (Gartman et al., 2016).
- The use of technology can also assist in reducing avian mortality. Coastal wind farms in Texas have been using avian radar technology to detect birds and shut down the wind turbines automatically if it perceives the birds to be in danger (Saidur et al., 2011). Further, endangered species are sometimes fitted with GPS transmitters that wind farms can use to track and adjust operations (McLendon, 2019). Additionally, systems using new technologies, such as distributed computing, IoT devices and artificial intelligence are increasingly harnessed to reduce bird mortality on wind farms (Gradolewski et al., 2021; Rogers, 2022).
- The area can also be modified to be less attractive to specific species (Bennun et al., 2021; Gartman et al., 2016). For example, activities can be conducted to reduce food availability for specific species, such as removing dead animals that could attract scavengers, or reducing habitat features for small mammals so as to avoid attracting raptors (Bennun et al., 2021) Inversely, *offsite* areas can be enhanced for these species by, for example, promoting the availability of prey through habitat management or the creation of roosting and breeding sites (Bennun et al. 2021).

Solar farm example: Enabling multi-functional uses, by co-locating solar farms and agriculture is increasingly considered as a way to potentially reduce competition between land-use for energy production, food production and biodiversity conservation.

Case studies

Case study: The Cattle Hill Wind farm

The Cattle Hill Wind Farm in Tasmania is using an aerial monitoring and detection system called IdentiFlight to reduce collisions with the Tasmanian wedge-tailed eagle, which is listed as endangered in the state. Construction of the 144 MW wind farm was completed in 2019 and started to power the grid in 2020 with 48 turbines, each standing 170 metres (Cattle Hill Wind Farm, n.d.; Vorrath, 2021). The approval of the project was conditional on the trial of the Identiflight camera technology. An 18-month trial was implemented (Rogers, 2022).

How does it work?

16 towers mounted with IdentiFlight units have been installed on-site which can shut down any of the 48 turbines. Fifteen towers are 7 metre tall, and one tower is 10 metre tall. The proprietary technology combines machine learning and AI technologies that are connected via an artificial neural network (IdentiFlight, n.d.). The technology works within seconds by detecting and photographing flying objects, using algorithms to identify the object. Once an eagle is detected, the technology tracks its flight path, recording height, speed, angle of approach and other data, while collecting images at ten frames per second. If an eagle's speed and flight path indicate a risk of collision with a wind turbine, a signal is sent to temporarily shut down that turbine (Rogers, 2022). Another signal is sent to restart the turbine once the eagle is no longer at risk.

A recent American study found that the use IdentiFlight led to an 82% reduction in the fatality rate at a study site in Wyoming, U.S.A. (Top of the World Wind power Facility) compared with the control site situated 15km away (McClure et al., 2021). Since installing the system in November 2019, Cattle Hill Farm has registered eight Tasmanian wedge-tailed eagle mortalities and zero White Bellied Sea Eagle, while a collision risk modelling exercise undertaken in 2010 predicted 14 eagle mortailites in four years (Cattle Hill Wind Farm, 2023).

Recent developments

In 2023, an additional 30 metre tower was installed on Cattle Hill Wind Farm in order to improve the visual coverage of a forested area present on the wind farm, where a number of eagle mortalities occurred. Since this additional tower was set up, no additional mortality was recorded. Additionally, a neural network was developed to identify the white bellied sea eagle. The IdentiFlight technology can now identify either species.

Birds and bat mortalities on wind farms have been a source of ongoing community concerns, including at Cattle Hill Wind Farm. We have noted elsewhere that there are few long-term studies on bird and bat mortality from wind farm projects. As such, the long-term monitoring of birds and bats mortalities – and the independent verification of outcomes – will be essential to build community trust in their effectiveness.

Case study: Agrivoltaics

Agrivoltaics (or Agrisolar) is the practice of installing solar PV into agricultural land (Mellon, 2021). It covers a wide range of approaches, the most common being incorporating solar panels with crop or livestock farming.

Large-scale solar farm projects can often conflict with meeting agricultural needs. The Food and Agriculture Organisation (FAO) estimates that food production will need to increase by 70% to support the estimated world population of 9.1 billion people in 2050 (FAO, 2009). Agrivoltaics could be a way to allow for the simultaneous production of renewable energy and agricultural products. Some potential benefits include:

-Additional source of income for landowners – either through leasing their land or selling the energy generated (if the system is privately owned) (Stark, 2022).

- Increased water conservation – panels can increase moisture retention and reduce irrigation requirements by up to 20% (Elamri et al., 2018).

- Certain crops benefit from increased shading – one study found that berries and fruit trees increased crop yield due to a decrease in solar radiation by 30% (Laub et al., 2022). However, the evidence base is still emerging, and this may only be true for certain crops under specific conditions. Indeed, a recent review of the literature on agricultural yield in agrivoltaic systems found that yields often decrease as the ground covering ratio increases (Dupraz, 2023).

Some examples of agri-voltaics include:

Numurkah Solar Farm (Victoria): the 128MW solar farm provides free grazing opportunities around the solar panels for farmers and 'lawnmowing' services for the solar farm (Hill, 2023) . Without the sheep, mowing the 1,200-acre farm can take up to seven weeks.

Domaine de Nideolères Vineyeard – Pyrénées-Orientales, France: The Escudié family have owned the Domaine de Nideolères vineyard for eight generations. The effects of climate change have led to the early ripening of the grapes, distorting the resulting wine's flavour profiles. In 2018, they installed 7,800 photovoltaic modules over 4.5 hectares of their vineyard. In collaboration with Sun'Agri, a French agrivoltaics company they carried out experimentation that produced the following results (Sun'Agri, 2021):

- 20% reduction in the plot's water consumption.
- Reduced impacts of heatwaves on the vineyard during the summer of 2019.
- Improved flavour profiles of the resulting wine.
- Installed sensors also allow for panel adjustment depending on the sun and the needs of the vines (Deboutte, 2021).

Agrivoltaics is still at an early stage in Australia and there is still limited data. There can be significant upfront costs and complex mounting systems which limit the potential for small-stage projects at this stage (Davey, 2022), further awareness is required amongst farmers (Rauline, 2021) and it is not suitable for all crops (e.g. wheat). The suitability of agrivoltaics needs to be determined on a case-by-case basis. Nonetheless, agrivoltatics may, under certain conditions, allow for energy and food production to occur together.

5. Minimising waste and land impacts at end-of-life and decommissioning of renewable energy technologies

Why is it important?

Materials that end up in landfill represent a missed opportunity to recycle and reuse to reduce the mining of virgin materials. Additionally, the disposal of renewable energy components, such as PV panels or batteries can release toxic substances such as lead, cadmium, mercury etc. that can leach into the environment (Azo Clean Tech, 2008; Gottesfeld et al., 2018; Sustainability Victoria, 2022; Zhao et al., 2021). While no studies were identified on the impacts of blades from wind turbines in landfill, they also contain toxic materials.

As the adoption of renewable energy technologies increases, more panels, blades and batteries will reach end of life. Approximately 100,000 tonnes of PV panels are projected to reach end-of-life by 2035 in Australia (Florin et al., 2020), while globally tens of thousands of tonnes of blades will need to be managed by 2050 (Majewski et al., 2022). Developing and mainstreaming the reuse and recycling of renewable technology components is therefore essential.

Current and emerging approaches

Lithium-ion battery example:

Modelling undertaken by UTS, for lithium-ion batteries used in electric vehicles, found that "*recycling has the potential to reduce primary demand compared to total demand in 2040, by approximately 25% for lithium, 35% for cobalt and nickel and 55% for copper*" (Dominish et al., 2021, p.i). The study also found that while it is technically feasible to recover lithium, cobalt, nickel, and copper from lithium-ion batteries, only cobalt and nickel – the most valuable ones – are commonly recovered, and they only represent a small proportion of the supply for the manufacturing of batteries. Metals recovered from other end markets are often recycled into the same products and are unlikely to be used for lithium-ion batteries, except for copper. Overall, lithium-ion batteries at the end-of-life are likely to become the main source of secondary metals for lithium-ion batteries. As such, ramping up the recycling of lithium-ion batteries is essential.

Wind power example:

The market for steel scrap and recycling for wind towers is relatively established, but this is not the case for blades. Blades are usually made of a composite resin that makes the separation of individual components difficult. Additionally, the blades decrease in value, even when they have been decommissioned successfully (Wind Energy Technologies Office, 2021). Those factors make blades hard to recycle. Current decommissioning and disposal practices only allow 30% of materials used in turbine blades to be reused as new composite materials (Majewski et al., 2022). However, projects are emerging to refurbish and recycle wind blades.

Solar power example:

Reuse markets for PV panels are still immature in Australia, due to regulatory barriers (i.e. reused panels are ineligible for renewable energy certificates making them less financially attractive) and low economic incentive (i.e. low costs of PV panels) (Salim et al., 2023). However, recycling options are emerging. For example, Reclaim is using a combination of mechanical processing and pyrolysis to break down solar panels into their components and recover materials like aluminum, copper, glass, plastics, silver, lead and silicon (Reclaim PV Recycling, 2021). Additionally, trials are occurring to develop end-markets, such as the New South Wales *Circular Solar Trial* project which is funding a novel solar panel recycling process and activating end-markets for recovered solar panel glass (PV Industries, n.d.). Innovation is likely to occur in global markets and the role for Australia will be to ensure local regulation and approaches reflect and enable advancements.

Case studies

Case study: Extending the life of wind turbines

Offshore wind project operator, Momentum, refurbished turbines and extended the life of a wind farm (Bockstigen in Gotland, Sweden) as an alternative to recommissioning with new turbines. Bockstigen Offshore Wind Farm is a 550kW wind park built 4km off the coast of the island of Gotland in 1998. In 2017, the decision was made to extend the wind farm's lifespan by at least an additional 15 years by replacing the existing turbines with refurbished used ones. The original tower, transmission cables and foundations were kept. The nacelles, 38m blades and controllers from the old turbines were replaced with refurbished nacelles, 47m blades and new controlling and monitoring systems (Gerdes, 2018). By November 2018, the five turbines were operational again (Momentum Clean Energy Solutions, n.d.).

This partial repowering was the first of its kind done in the area and proved its:

- Technical viability – it is possible to replace individual components to extend the lifetime of a project, especially under the challenging environmental conditions that offshore wind farms present.
- Financial viability – the investment has an expected long-term double-digit Internal Rate of Return on gross investment without subsidy.
- Operational viability – the new components doubled the annual electricity generation from 5,000 MWh to 11,000 MWh, demonstrating that older wind infrastructure can be retrofitted as new, more efficient technology is developed (Gerdes, 2018).

Partial repowering has proven to be viable for older turbines but still needs to be demonstrated for modern, larger wind turbines.

Case study: Siemens Gamesa – RecyclableBlade

In 2022, Siemens Gamesa (Spain) announced their RecyclableBlade – the world's first fully recyclable wind turbine blade – was ready for use in offshore and onshore wind power projects. The recycling process for the RecyclableBlade involves using a mild acidic solution to disassemble the parts at the end of its life (Siemens Gamesa Renewable Energy, 2022). These materials can then be used in construction, consumer goods or cars (Siemens Gamesa Renewable Energy, 2022). The RecyclableBlade innovation is part of Siemens Gamesa's Sustainability Vision towards 2040, to produce fully recyclable wind turbines by 2040 (Siemens Gamesa Renewable Energy, 2018).

Case Study: Birmingham Extreme Robotics Lab, University of Birmingham

The Reuse and Recycling of Lithium-Ion Batteries (ReLiB) is a project being conducted in the UK involving a consortium of 50 scientists and engineers as well as 14 industry partners. Led by the University of Birmingham, they are working together to improve Li-ion battery recovery, specifically from electric vehicles. Researchers at the Birmingham Extreme Robotics Lab use robotics technology to remove, dismantle and recover li-ion battery cells from electric vehicles (Harper et al., 2019; IER, 2020).

The novelty of this technology is that these robots were originally developed for nuclear power plants and are resistant to high levels of radiation. Automating the recovery process using these state-of-the-art robotics, computer vision and artificial intelligence eliminates the health risks posed to humans, reduces costs and improves the separation process, enhancing the purity of the recycled materials (Harper et al., 2019).

Recycling batteries in this way reduces the need for primary materials and enhances material supply and efficiency (Jacoby, 2019).

6. Avoiding impacts from mining and manufacturing in renewable energy supply chains

Why is it important?

The scaling up of renewable energy will lead to a major expansion in mining and manufacturing of critical minerals – with the potential for large impacts on societies and environments where mining occurs. A recent study by Sonter et al. (2020) found that the increasing demand for materials use for renewable energy is likely to pose new threats to habitat and wildlife as sites for critical minerals (e.g. cobalt, lithium, copper, nickel, and rare earth metals) are frequently located in areas of high biodiversity.

- *Solar energy example*: The production of solar panels currently uses minerals such as silicon, glass, copper, silver, indium and tellurium. The mining, processing, and manufacturing of those materials use large amounts of water, generates wastewater containing harmful liquids (fluorine) and metals (silicon containing chromium) (Qi & Zhang, 2017) and risks water contamination (e.g. acid mine drainage, improper wastewater discharge and disposal of tailings) and soil erosion (IEA, 2022).
- *Battery storage example*: Similarly, the extraction, processing and manufacturing of critical battery minerals has widespread impacts on water and soil. Large volumes of water are used at the mining, processing and manufacturing stages. At each stage, there are risks of water contamination from toxic chemicals that need to be carefully managed (Manhart et al., 2019; United States Environmental Protection Agency, n.d.). One study analysing the soil located around battery manufacturing and recycling plants in Africa, found that the lead leaching into the soil used for agricultural purposes had reached toxic levels (Gottesfeld et al., 2018). Mining critical battery metals can also destroy the structure of soils, remove large volumes of soil for roads (Manhart et al., 2019) and cause soil contamination (Brooks, 2021; Dominish et al., 2019) which can impact food quality, and ultimately, food security (Wuana & Okieimen, 2011).
- *Green hydrogen example:* Green hydrogen also generates impacts on water and soil. For example, Nickel and zirconium are essential materials for the electrolysers used to produce green hydrogen (Angeles-Olvera et al., 2022, IEA, 2022. However, producing nickel is an energy intensive process and generates large amounts of solid waste (smelter slags and leaching residues). This can lead to soil and surface and ground-water contamination if handled improperly (Bartzas et al., 2021), such as in Obi Island, Indonesia where the world’s largest nickel mine is located (Firdaus & Levitt, 2022). The environmental impacts of zirconium have not been studied in great detail, but if it seeps into soil, it has been reported to negatively impact soil-plant systems (Shahid et al., 2013).

These new threats to ecosystems could be considerable if no mechanisms are put in place to avoid and reduce impacts.

Current and emerging approaches:

Responsible sourcing practices for solar panels, wind farms and batteries which focus on both environmental and social dimensions are starting to gain momentum, including:

- **Increasing traceability**: Understanding where materials are being sourced is the first step to understand risk of environmental impacts from mining. However, transparency is challenging owing to the complex nature of supply chains and the multiplicity of stakeholders, including mine operators, traders, smelters, and component manufacturers. For example, although the majority of cobalt is mined in Democratic republic of Congo, most is processed in China where it is blended together during the refining process (RAID and CAJJ, 2021). Many manufacturers, particularly EV manufacturers, are moving towards purchasing directly from mines and supplying raw materials to their component manufacturers. The idea of developing ‘passports’ for renewable energy technology is gaining momentum. A passport would provide information about each material that comprise the technology, which could facilitate its recycling and reuse in the future and encourage the mining and metals to improve their sustainability credentials.
- **Sourcing materials from lower risk countries**: Manufacturers are increasingly procuring minerals for batteries from countries like Australia, Canada, the EU and US with higher regulatory standards (Dominish et al., 2019). But mining projects in those countries may still have risks of environmental and human rights impacts. For example, in the US a large proportion of nickel, copper, lithium and cobalt reserves are

located in close proximity to Native American reservations (Block, 2021). Relocating sourcing to the "global north" does not address the existing harms within supply chains (Riofrancos, 2022) and can have negative impacts in disadvantaged communities where mining currently occurs.

- **Standards and certifications**: Downstream consumers of metals can help to drive improvements to the environmental and human rights impacts of mining operation. A best practice approach for responsible minerals sourcing is a commitment to source from mines that follow strict environmental and human rights standards via independent, third-party certification and standards schemes. (see the Initiative for Responsible Mining Assurance case study below). However, it is important to note that strong environmental laws in mining are the most important mechanisms – voluntary standards and certification schemes aim to fill this gap until the bar for biodiversity laws is higher.

While responsible sourcing can contribute to reducing the negative impacts of mining for critical minerals, reducing the demand for critical minerals is the first-best solution. For example, the demand for private vehicles and batteries can be reduced through for the use of car sharing, active and public transport, improving material efficiency and increasing the use of recycled content.

It is therefore essential to consider more circular economy options in the mining sector to shift the focus away from a "take-make-dispose" mentality towards an industrial mindset that explores opportunities for mining waste to be reprocessed, reused, and recovered. For example, urban mining aims to recover the raw materials from e-waste already in circulation. A shift towards a circular mining economy could provide opportunities to add value beyond a traditional export economy to develop a stronger manufacturing and processing industry in Australia.

Case studies

Case study: The Initiative for Responsible Mining Assurance

The Initiative for Responsible Mining Assurance (IRMA) provides independent, third-party assessments and auditing of industrial scale mine sites. In 2018, IRMA launched its *Standard for Responsible Mining* which considers environmental impacts, governance, human rights, labour, and safety conditions at the mine site.

The *Standard for Responsible Mining* was developed through a multi-stakeholder consultation process that recognised and improved upon the principles contained in existing certification and standards schemes. Six stakeholder groups, including mining companies, purchasing companies, investors, impacted communities, labour organisations and non-profit organisations (environmental and social) held equal authority to identify the topics and content of the standard. The final standard reflects the consensus reached between them.

The Standard for Responsible Mining is designed to assess a mine in four principles:

- Business integrity
- Planning for positive legacies
- Social responsibility and
- Environmental responsibility

The Environmental Responsibility principle covers waste and materials management, water management, air quality, noise and vibration, greenhouse gas emissions, biodiversity, ecosystem services and protected areas, cyanide, and mercury management.

The Planning for Positive Legacies principle (2) includes a condition on Free, Prior and Informed Consent (FPIC) from Indigenous peoples, recognised as not merely a stakeholder, but as rights holders whose entitlements include the right to self-determination, property, culture, and religion in relation to lands, territories and natural resources, including sacred places and objects (IRMA, 2018).

Mining companies can use the standard as a 'guidebook' to what stakeholders expect of mining operations when it comes to responsible practices. For mine sites which undertake a third-party audit, it allows for a more rigorous evaluation than other mining standards, as it provides best-practice, specific and detailed information when evaluating whether a mine site meets the standard. Additionally, the auditor needs to score each requirement and provide a rationale for their score, which allows for any stakeholder reviewing the report to understand how a specific rating was achieved.

The main challenge encountered by IRMA is to have sufficient participating mines using the standard to enable a sector wide shift toward responsible mining practices. The renewable energy sector has major purchasing power and could consider IRMA as an opportunity to drive a change toward responsible mining practices. Early signs of this shift are visible with EV companies becoming members of IRMA, but as of April 2024, there is only one renewable energy company which is a member (Ørsted).

See Appendix VI for further details on the drivers of change, factors of success and challenges in developing the project.

Case study: European Union Batteries Regulation

The European Union (EU) Batteries Regulation (Regulation (EU) 2023/1542)[3] came into effect in August 2023 to better regulate the EU's batteries supply-chain to drive better end-of-life management. The regulation takes a life cycle approach to lower the carbon footprint, raw material inputs, and harmful substances used in batteries, increase collection for reuse in different applications (e.g. reuse of EV batteries for stationary storage once they have depleted their charging potential), and recycle valuable critical minerals, such as cobalt, lithium, and nickel (Council of the EU, 2023).

The regulation introduces Extended Producer Responsibility mechanisms to place greater responsibilities on manufacturers, producers, importers, and distributors of all types of batteries sold within the European market. This legislation introduces changes to regulation across four main areas, including sustainability and safety (e.g. stricter conditions for hazardous substances like mercury, cadmium, and lead), supply chain management (e.g. operators must verify the provenance of battery raw materials), labelling andinformation (e.g. digital battery passport) and end of life management (e.g. recycling efficiency targets).

There will also be stronger enforcement of the 'right to repair', as there will be stronger regulation to ensure that portable batteries in appliances are easier to remove and replace at their end of life (Directorate-General for Environment, 2023).

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[3] Regulation (EU) 2023/1542 of the European Parliament and of the Council of 12 July 2023 Concerning Batteries and Waste Batteries, Amending Directive 2008/98/EC and Regulation (EU) 2019/1020 and Repealing Directive 2006/66/EC, 2023)

Concluding remarks

- Knowledge on the impacts of renewable energy technologies on habitat, wildlife, soil and water is incipient and further research is needed to systematically characterise, understand and quantify those impacts in different ecosystems.

- A range of practices already exist to mitigate the impacts of renewable energy technologies on habitat, wildlife, soil, and water. It is essential for those existing practices to be mainstreamed in projects through regulations, knowledge sharing and collaboration. Additional research and development is also needed to improve existing practices.

- To minimise the site-based impacts of renewable energy technologies (footprint of the infrastructure), strategic planning has emerged as an essential tool to avoid areas of high biodiversity and cumulative impacts. The Renewable Energy Zones could be conducive to the development of a strategic planning approach to renewable energy infrastructures, by identifying zones where the development of renewable energy technologies will have the lowest environmental impacts.

- Reducing impacts along the supply-chain can be achieved by adopting a circular economy approach to the provision of minerals used in renewable energy technologies, reducing the demand for minerals, and facilitating their reuse and recycling. Additionally, the development and adoption of responsible sourcing practices is necessary to ensure that raw materials are mined in a way that mitigate negative social and environmental impacts.

- The implementation of better practices presented above can only lead to better biodiversity and climate outcomes if they are undertaken in the context of a broader range of systems change, which involve shifts in our economy and regulations (CLEANaction, 2023). While those considerations are beyond the scope of this report, it is important to remember that the implementation of better ecosystem-related practices for the energy transition, cannot happen in isolation from broader systems change.

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