Small Scale Study of the Impacts of Climate Change Mitigation Measures on Biodiversity

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*Photo: Yvonne Buckley, Marsh Helleborine (*Epipactis palustris*) at Mountlucas Wind Farm (Bord na Móna)*

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Executive Summary

Ireland must transition urgently to a low-carbon economy to avoid the devastating global and national impacts of unimpeded climate change. Simultaneously, we are faced with a biodiversity crisis and need equally urgent action to prevent further biodiversity loss and ensure restoration and rehabilitation of critical habitats and ecosystems. As we move to act on climate change, we should prevent further pressure on biodiversity and explore options that provide synergistic gains for both climate and biodiversity change mitigation and adaptation, through consideration of the effects of infrastructure development, land-use change and the potential of nature-based solutions. Ireland's Biodiversity Climate Change Sectoral Adaptation Plan outlines biodiversity policy in the context of climate change and identifies key actions that need to be taken to support biodiversity (Department of Culture, Heritage and the Gaeltacht, 2019). Here we review the key potential impacts on biodiversity of climate mitigation measures in energy and land use including the development of renewable energy sources such as offshore wind, onshore wind and solar, and bioenergy. We also discuss the potential impacts of afforestation and land use change with reference to current targets and plans for Ireland. We have identified several potential "win-win" strategies for both climate mitigation and biodiversity conservation. We recommend the promotion of renewable energy methods with lower negative ecological impacts, such as offshore wind and the incorporation of solar into the built environment or other intensive land uses. Additional potential "win-wins" include the rehabilitation of natural carbon stores and sinks, afforestation with native trees, agroforestry and extensification of livestock farming. It is critical that all renewable energy projects are sited appropriately, and that action-based monitoring is employed across all measures. Climate mitigation strategies should be implemented in a "Right Action, Right Place" framework to maximize positive benefits for both climate and biodiversity.

Offshore Wind

The development and expansion of offshore wind to produce renewable energy is necessary to meet our climate mitigation targets. There are potential negative impacts to biodiversity including disturbance during construction and displacement of birds from important foraging or migration sites. However, when designed with biodiversity in mind, potential negative impacts on biodiversity can be avoided, minimized, and mitigated. Additionally, there are several potential opportunities for biodiversity protection and restoration, making this renewable energy source particularly viable as a potential **win-win** for both climate and biodiversity. For example, offshore wind farms can be designed to provide habitat and protection for marine wildlife such as fish and invertebrates (Leonhard & Pedersen, 2006; Wilhelmsson *et al.*, 2006). In line with this, long-term studies have shown that fish species abundance and diversity increase near turbines (Stenberg *et al.*, 2015). Furthermore, wind farms can be strategically located to function as marine protected areas that shelter areas from destructive activities such as bottom trawling and dredging. Overall, research to date suggests that the positive benefits for both climate mitigation and biodiversity conservation of offshore wind development outweigh the negative impacts. We have identified several recommendations that can be used to ensure that offshore wind installations minimize negative impacts and maximize potential positive biodiversity impacts:

Recommendations (Construction)

1. While individual wind farm footprints are low, consider the timing of development to minimise industry-wide impact during the construction of multiple wind farms.
2. Marine planning strategies such as the National Marine Planning Framework that explicitly include marine biodiversity protection and restoration are necessary.
3. Use existing sensitivity planning tools and develop new mapping tools to identify areas unsuitable for offshore wind in advance of construction.
4. Time construction to have the least possible overlap with important Cetacean migration, feeding, or breeding activities.

5. Investigate the potential to implement floating wind farm technology to minimise sea-bed disturbance.
6. Assess pile driving effects in key spawning ground for fish stocks and use exclusion zones to promote recovery of stocks.
7. Use existing technology to reduce the noise created by construction activities (e.g., air bubble curtains).
8. Associated onshore support infrastructure for offshore wind should be developed with sensitivity to biodiversity impacts.
9. Design offshore infrastructure to provide habitat for biodiversity (artificial reefs).

Recommendations (Operation)

1. If a wind farm must be constructed in an important bird migration pathway, alternative migration corridors between wind farms must be available.
2. Better monitoring systems should be developed to monitor risk and risk avoidance measures (e.g., temporary curtailment) should be implemented.
3. Maximise positive biodiversity impacts of wind farm associated fisheries exclusion zones.

Recommendations (Decommissioning)

1. Maintain and upgrade the wind turbines as necessary to prevent or delay decommissioning.
2. Plan for decommissioning to maintain biodiversity benefits achieved through artificial reef formation.

Onshore Wind

Onshore wind is currently the main renewable energy source in Ireland and there are plans to increase the amount of energy from onshore wind up to 8.2 GW by 2030 to meet climate mitigation targets. The key potentially negative impacts to biodiversity are destruction and/or loss of sensitive habitats, habitat fragmentation, and injuries to bats and birds. Most potential impacts can be avoided, minimized, or mitigated with appropriate consideration for biodiversity during the planning of site locations of wind farms. It is especially important to avoid placement on deep peat / vulnerable peatland areas, sensitive areas, or areas that are important for sensitive species. When implemented appropriately, the development of onshore wind presents opportunities for biodiversity restoration and protection. Areas surrounding the wind turbines can be rehabilitated into natural habitats and/or managed for biodiversity and ecosystem service provision. Wind farms could be co-located with areas already under intense land-use, such as agriculture. Farmers can generally continue to use around 95% of the land to plant crops or graze livestock near wind turbines. The siting of wind farms in such areas with already lower levels of biodiversity would remove some conflicts arising from inappropriate siting on high biodiversity value and sensitive sites. To minimize potential negative impacts, and maximize potential benefits to biodiversity, we recommend the following:

Recommendations (Construction)

1. New wind turbines (and repowering) should only be constructed in appropriate locations that do not compromise biodiversity or WFD obligations.
2. Avoid vulnerable and protected peatland and other nature protected areas.
3. Ensure that the site selection process and turbine placement is informed by the existing Special Areas of Conservations and Special Protected Areas, as well as the functional connectivity of isolated resources necessary for these protected sites.
4. Include migration pathways or commuting/foraging routes for key species in planning processes.
5. Co-locate wind with more intensive agricultural land uses.

Recommendations (Operation)

1. Encourage energy-environment/PFES/community schemes to promote enhancement of biodiversity in wider local landscape.
2. Real-time/smart monitoring to inform strategic curtailment during times of high bat and bird activity.
3. Community engagement in local biodiversity enhancement schemes.

Recommendations (Decommissioning)

1. Maintain and upgrade the wind turbines as necessary to prevent decommissioning

Solar

The 2019 Climate Action Plan includes increasing energy produced via solar photovoltaics (PV) to 1.5 GW of installed capacity by 2030 to reach our climate mitigation targets. This has the potential for negative impacts on biodiversity. Key potential negative impacts include land-use change, habitat loss, and habitat fragmentation. Proper management and planning can ensure that key impacts are avoided, minimised, or mitigated at every stage of development. However, almost all potential negative impacts of developing solar can be avoided by limiting its deployment to the built environment. This includes incorporating solar panels into existing infrastructure such as buildings, car parks, and residential houses. Initiatives such as the micro-generation grant scheme for PV are already in place to promote the installation of solar panels on individual homes (*Climate Action Plan*, 2019), and such programmes should continue to be developed and supported. For larger developments, siting solar facilities in areas already degraded and/or developed by humans can reduce the magnitude of adverse impacts (Hernandez *et al.*, 2015a). Therefore, taking a “right action, right place” approach by limiting solar facilities to the built environment could be a significant **win-win** for climate and biodiversity in Ireland. Additionally, there are opportunities to create functional space beneath and between solar panels to support other ecosystem services such as pollination and/or the utilisation of livestock grazed land to support solar PV. We recommend the following to minimize potential negative impacts and maximize potential positive impacts:

Recommendations (Construction)

1. Solar panels should be incorporated into existing built infrastructure.
2. Farms of solar panels on agricultural or undeveloped land should be discouraged, because of the large areas of land required for their operation leading to direct impacts on biodiversity and indirect impacts through the displacement of other land-uses and intensification of semi-natural areas.
3. If utility-scale solar energy systems cannot be avoided, they should be strategically placed to avoid sensitive areas and minimize negative impacts on biodiversity.

Recommendations (Operation)

1. The functional use of land beneath panels should be promoted (e.g., low intensity grazing).
2. Alternatives to herbicide use to manage vegetation below and between solar panels should be developed and used.
3. Management for tolerant elements of biodiversity between, around and beneath solar panels

Bioenergy

The 2019 Climate Action Plan aims to set a target for biogas and biomethane development and develop and stabilise the indigenous supply of biomass for renewable heat and combined heat and power. However, the development of bioenergy could have negative impacts on biodiversity. The primary concerns in Ireland are that the cultivation of bioenergy crops and creation of biomass plantations are land-use intensive and could require a significant amount of water (Fritsche *et al.*, 2010; Beringer *et al.*, 2011). These land-use and water-use requirements have the potential to compromise our existing obligations to N2000 and WFD. Furthermore, several lines of evidence indicate that bioenergy has the potential to be poorly implemented, leading to this sector directly and indirectly producing more greenhouse gas emissions than traditional fossil fuels (Searchinger *et al.*, 2009). While the development of bioenergy in Ireland offers some limited opportunities for biodiversity protection (mainly increasing pressure for the development of sustainable agricultural practices) we did not find evidence to support its utility as a win-win for climate and biodiversity. We recommend the following to minimize potential negative impacts:

Recommendations (Construction)

1. Major land-use change should be avoided to minimise soil carbon losses (e.g., conversion of unimproved grassland to improved grassland or arable).
2. Avoid natural and semi-natural areas.
3. Prioritise the use of waste products from existing land-uses for bioenergy.

Recommendations (Operation)

1. Mandate the protection of important biodiversity landscape features (hedgerows, ponds, buffer strips, woodland edges etc.)

Afforestation

Reforestation of degraded forests and afforestation of previously cleared areas are necessary to meet our climate mitigation targets, as forests can slow the accumulation of greenhouse gas emissions by sequestering carbon (Rudel *et al.*, 2005). The Climate Action Plan aims to plant 8,000 hectares of new forest each year to reach an ultimate target of 18% cover by 2046 (*Climate Action Plan*, 2019). If the right kinds of trees are planted in the right areas this afforestation target could have substantial positive impacts on biodiversity and water quality, however implementation is key to maximizing these positive effects (Allen & Chapman, 2001; Sacco *et al.*, 2021). In addition to afforestation, there is high potential for agroforestry (i.e., the intentional integration of trees and shrubs into crop and animal farming systems) in Ireland. Agroforestry can improve habitat quality and connectivity in the landscape and promote biodiversity. Hedgerows, scrub and woody habitats on farmland represent a vital ecological network supporting biodiversity in the agricultural landscape. Meeting the EU's 2030 Biodiversity Strategy's target of 10% of farmland area being 'high diversity landscape features' would require protection of existing biodiversity, restoration of biodiversity on intensive farms where habitat cover tends to be low, and an increase in the sequestration and carbon storage associated with hedgerows and woody farmland habitats. Given the utility of afforestation as a potential **win-win** for climate, biodiversity, and water, we should consider increasing afforestation targets with an emphasis on appropriate implementation and native species use. We recommend the following to maximize the positive benefits of afforestation:

Recommendations

1. Avoid afforestation of naturally open habitats and deep peat soils
2. Restoration of degraded natural and semi-natural woodlands to improve carbon and biodiversity states
3. Set targets for native mixtures in plantation forests
4. Avoid using planted trees as bioenergy crops
5. Avoid displacing land-use (e.g., intensifying land-use on natural and semi-natural habitats)
6. Disincentivise the use of fire to clear land
7. Promote agroforestry initiatives
8. Rehabilitate peatlands on failed plantation sites
9. Prioritise and extend LiDAR surveys of Teagasc Signpost farms to estimate

carbon sequestration of hedgerows and woody habitats on farmland

Other land use change

Peatland restoration and rehabilitation

About 5-6% of our peatlands have been drained for industrial peat extraction. However, Ireland has recently realized the negative impacts of peat extraction for climate and biodiversity and has ceased peat extraction for fuel. Many of these bogs will be decommissioned and rehabilitated so that they can be returned to semi-natural states to reduce GHG emissions and provide for regeneration of habitats for biodiversity. However, there is still a demand for, and extraction of, horticultural peat at a commercial scale. Smaller scale regional and domestic turf extraction is also ongoing for use in home heating. This continued peat extraction could have severe negative impacts for biodiversity. Regulation of peat extraction (including turf) would help prevent the expansion of extraction, and resulting consequences for climate, water and biodiversity. Furthermore, the rehabilitation (rewetting and potential restoration where feasible according to SER Standards) of decommissioned bogs should be a top priority for climate mitigation and biodiversity conservation in Ireland as this is a **win-win** nature-based solution that would have strong and immediate positive impacts on our environment.

Recommendations

1. Promote and fund the rehabilitation of decommissioned industrial peatlands
2. Further regulate all peat extraction, including turf and horticultural peat production
3. Consider how turbary rights can be altered (to carbon & biodiversity sequestration rights) or purchased to reduce small scale peat extraction.
4. Identify and map peatland areas related to turf and horticultural peat extraction (non BNM areas)

Livestock Farming

Current policies put forth in Teagasc's mitigation strategy allow for continued increase in dairy farming. Through the heavy soils programme, Teagasc envision a further 10% of grassland in Ireland will come under intensive pasture management allowing a concomitant increase in cattle. The intensive pasture management typical of Irish dairy systems requires high nitrogen fertilizer inputs, which contribute to nitrous oxide emissions and negatively impact biodiversity and water quality due to runoff. Drainage of heavy soils will also likely negatively impact high nature value farmland – see Drainage of Heavy Soils – thus negatively impacting biodiversity. Thus, an effective mitigation strategy that would simultaneously benefit biodiversity is preventing dairy expansion.

Recommendations

1. Prevent dairy expansion
2. Use new CAP to incentivise extensification of livestock farming and provision of alternative ecosystem services
3. Reduce the amount of N applied to pastures
4. Use clover and multi-species swards to reduce need for nitrogen application

Drainage of heavy soils

Teagasc have implemented a 'Heavy Soils Programme' that aims to drain 10% of Ireland's total grassland by 2030 to increase the quality of agricultural land. It has been suggested that this programme will be beneficial for climate mitigation as the drainage of mineral soils can result in a direct reduction of N_2O emission. However, the benefits for climate mitigation are limited, as draining organic and/or peat dominated soils results in significant emissions of the CO_2 that is naturally sequestered in such soils. The drainage of mineral soils could also lead to an increase in N leaching (Teagasc Greenhouse Gas Working Group, 2019). There are substantial potentially negative impacts that could result from this scale of soil drainage. For instance, there is likely to be significant overlap between heavy soils and High Nature value farmland (‘HNV Distribution’, 2015). Therefore, draining large percentages of the countries heavy soils will negatively impact the distribution and coverage of high nature value farmland, and consequently negatively impact biodiversity. Current considerations for biodiversity include planting multi-species swards (i.e., or mixtures of three or more species) as forage. This practice does have environmental benefits, as it can produce similar yields to grass monocultures but with a steep reduction or elimination of fertilizer input. However, multi-species swards are not a realistic replacement for natural biodiversity.

Recommendations

1. Multi-species swards should not be considered as a replacement for high nature value/semi natural grasslands but can be effective in reducing fertiliser needs.
2. Assess whole of life-cycle impact on GHG due to drainage of heavy soils and subsequent intensification for livestock farming.

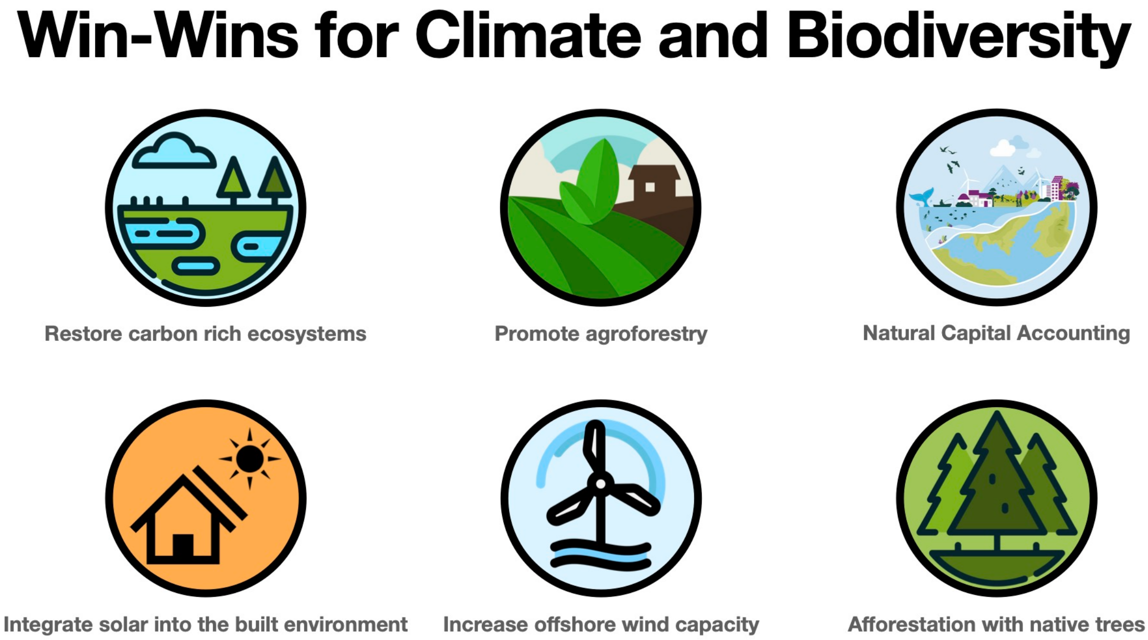

Figure 1. Infographic representing key "win-win" strategies for both climate mitigation and biodiversity

Conclusions

Climate change, biodiversity, and human activity are interconnected. Part of the reason that we have the current global climate and biodiversity crises is that the environment outside of human societies was considered an externality. We cannot address either crisis without changing this outlook. The solutions must be integrated, and biodiversity considerations must be incorporated in to our every land use through a natural capital accounting approach. Biodiversity must be integrated into action addressing climate change. This requires that we bring ecological considerations for all plans and projects to the design phase, including location considerations. This strategy helps to avoid biodiversity conflicts with national strategic infrastructure works as we can eliminate obstacles in advance, such as conflicts with the EU Habitats and Birds Directives or potential impacts to key species such as Hen Harrier or bats.

We need to develop biodiversity-friendly renewable energy by prioritising renewables that are the least damaging and ensure that infrastructure development is carried out as sensitively as possible to protect, restore, and enhance biodiversity. This "mitigation hierarchy" should focus first on avoiding negative impacts and only then minimising harm, remediating damage, and, if these efforts are insufficient, damage at the focal site can be offset through biodiversity improvements in another site (Arlidge *et al.*, 2018). We should promote renewable energy methods with minimal negative ecological impacts, such as offshore wind and the incorporation of solar into the built environment. Additionally, appropriate siting is critical for all renewable energy projects. It is important that projects are carefully implemented so they do not compromise biodiversity and have unintended negative effects on carbon emissions (e.g., bioenergy). To ensure best practices and accountability, we need action-based monitoring for all measures. The monitoring processes need to focus on an action response model if impacts are identified, rather than the current scenario where damage is recorded year after year with no action.

In this review we have identified several projects that when implemented correctly are "win-win" measures for climate and biodiversity (Fig. 1). These projects should continue to be supported and their expansion should be considered. Additionally, we have identified research gaps (summarized in Appendix Table 1) that highlight areas where more information is needed before we can accurately assess impacts and/or effective mitigation strategies. We have also outlined the key potential negative impacts of renewable energy projects on biodiversity. The most substantial negative impact across all renewable energy sources is land-use change to a more intensive land-use. Land-use change has substantial, long-term, negative impacts on climate and biodiversity. We should avoid converting tracts of terrestrial land to more intensive land uses for climate mitigation facilities and we should avoid the displacement of agriculture into currently natural and semi-natural areas (in Ireland and internationally into areas important to global climate and biodiversity like rainforest). To do this effectively, we need a national land use strategy. By assessing the effects of renewable energy developments in the context of national and regional land-use we will ensure that "death by 1000 cuts" does not occur, and we will maximize the potential for positive outcomes for both climate and biodiversity.

2. Background

Ireland must transition urgently to a low-carbon economy (i.e., decarbonisation) to avoid the devastating global and national impacts of unimpeded climate change (IPCC, 2018). We need equally urgent action to prevent further biodiversity loss and ensure restoration and rehabilitation of critical habitats and ecosystems (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, 2018). Both climate and biodiversity crises threaten life support systems, livelihoods, and quality of life for people through their direct and indirect impacts on provisioning (food, shelter), regulating (climate, nutrients, pollination) and cultural (spiritual, aesthetic, relational) ecosystem services (Chapin III *et al.*, 2000; Díaz *et al.*, 2006; Jones *et al.*, 2019) . The biodiversity and climate crises are entwined in a complex system of feedbacks, with biodiversity as part of the earth system regulating climate, and climate determining biodiversity patterns and trajectories. As we move to act urgently on climate change, we need to prevent further pressure on biodiversity and explore options that provide potential synergistic gains for both mitigating the climate and biodiversity crises, through consideration of the effects of renewable energy infrastructure development, land-use change and the potential of nature-based solutions.

2.1 Biodiversity in Ireland

In May 2019 the Dáil declared a climate and biodiversity emergency. Although the public awareness of biodiversity loss and change has increased and cross-sectoral engagement in biodiversity action has improved, the status of biodiversity in protected areas, seas and the wider countryside is in poor condition and continues to decline (NPWS Article 17 EU Habitats Directive report 2019, National Biodiversity Action Plan (2017-2021)). While the decline of rare and threatened habitats and species is important to address, the erosion of natural capital stocks underpinning widely distributed beneficial ecosystem services is also concerning. Biodiversity decline and habitat destruction caused by land-use change, over-harvesting, pollution and intensive agriculture throughout the wider countryside threaten the provision of critical services such as: clean drinking water, flood mitigation and pollination, that underpin current and future economic activity in tourism, agriculture, forestry, as well as providing for quality of life for citizens. The National Biodiversity Forum's commentary on Ireland's progress on biodiversity action highlights the improvement of governance and stewardship of biodiversity as a key recommendation (www.biodiversityimpactplan.ie). Under this recommendation there needs to be improved policy coordination, mainstreaming of biodiversity into decision-making and ensuring accountability for targets.

The recognition for urgent climate action has led to policy actions such as Ireland's participation in the Paris Agreement on Climate Change (UNFCCC, 2015). To meet our decarbonisation goals, Ireland has developed a Climate Action Plan (*Climate Action Plan*, 2019), to achieve a net zero carbon energy systems objective by 2050. Specific actions include increasing the amount of electricity generated from renewable sources from 30% to

70% by 2030, increasing the number of electric vehicles used for personal and public transport, reducing emissions from agriculture and establishing 8,000 hectares of newly planted trees (i.e., afforestation) per year (*Climate Action Plan*, 2019).

In addition to the development of ambitious climate goals, Ireland has recognized the importance of conserving biodiversity and has made commitments to increase the protection of species and their natural habitats[1] The National Biodiversity Action Plan (2017-2021 - currently being renewed) sets out actions across seven objectives to achieve the vision (*National Biodiversity Action Plan*, 2017). The Biodiversity Climate Change Adaptation Plan (Department of Culture, Heritage and the Gaeltacht, 2019) recognises the need to put in place actions to protect biodiversity from climate change as well as considering biodiversity as an adaptation tool for other sectors, with the potential for multiple co-benefits including water regulation and purification and carbon sequestration.

We need to decarbonise the economy in ways that that support our biodiversity ambitions and obligations. Here we review the key potential biodiversity impacts of climate change mitigation measures in the energy and land use sectors, throughout the planning and implementation cycle, with reference to current targets and plans for Ireland. Biodiversity impacts of renewable energy sources (offshore wind, onshore wind and solar, and bioenergy), afforestation, peatland restoration and rehabilitation, and land use change are addressed. We provide a set of insights for the Climate Change Advisory Council to consider when developing their recommendations on carbon budgets for Ireland to fulfil the national climate objective including the transition to a biodiversity rich economy.

[1] (EU Birds [Directive 2009/147/EC] and Habitats Directives (which provide for the Natura 2000 (N2000) network of protected areas), Marine Strategy Framework Directive (MSFD), EU Water Framework Directive (WFD), and EU Biodiversity Strategy (EC 1992; EC 2000; EC 2008 and EC 2009)).

Table 1. National and international biodiversity obligations and plans.

Directive/Strategy/Plan	Exemplar goals/activities
UN Sustainable Development Goals	17 SDGs, in particular Life on Land and Life in Water. Biodiversity action also benefits many of the other goals.
UN Convention on Biodiversity	Five strategic goals and 20 Aichi Biodiversity Targets.
EU Birds Directive	Conservation of species and their natural habitats through the establishment of protected areas (e.g., N2000). Appropriate Assessment of plans/policies likely to have a significant effect on a European site.
EU Habitats Directive	
EU Water Framework Directive	Protecting and improving water quality in surface waters and ground water, healthy aquatic ecosystems.
EU Marine Strategy Framework Directive	Good environmental status (including biodiversity)
EU Biodiversity Strategy	Put Europe's biodiversity on the path to recovery by 2030 for the benefit of people, climate and the planet.
EU Environmental Impact Assessment Directive [2011/92/EU] & Strategic Environmental Assessment Directive [2001/42/EC]	Environmental assessment of individual projects and public plans or programmes. Environmental assessment prior to approval.
Wildlife Act 1976 & Wildlife (Amendment) Act 2000	Designation of protected sites & species. Strengthened conservation measures and statutory recognition to international obligations (e.g., Convention on Biodiversity, CBD).
National Biodiversity Action Plan	That biodiversity and ecosystems in Ireland are conserved and restored, delivering benefits essential for all sectors of society and that Ireland contributes to efforts to halt the loss of biodiversity and the degradation of ecosystems in the EU and globally
Climate Action and Low Carbon Development (Amendment) Bill 2021	National Climate Objective: "The State shall, so as to reduce the extent of further global warming, pursue and achieve, by no later than the end of the year 2050, the transition to a climate resilient, **biodiversity rich**, environmentally sustainable and climate neutral economy."
Biodiversity Climate Change Sectoral Adaptation Plan	Protect biodiversity from the impacts of climate change and to conserve and manage ecosystems so that they deliver services that increase the adaptive capacity of people and biodiversity while also contributing to climate change mitigation.

2.2 Main threats to biodiversity in Ireland

Most Irish habitats listed on the Habitats Directive are in Unfavourable status and almost half are demonstrating ongoing declines (Fig. 2). The main threats and pressures on EU protected habitats and species in Ireland are from agriculture (including ecologically unsuitable grazing levels), forestry and fisheries, natural system modifications (including drainage and/or cutting of peatlands), mining and quarrying (including peat extraction), climate change, pollution, and invasive and problematic species (Fig. 3) (NPWS, 2019). Habitat loss is also recognised as an ongoing pressure on biodiversity.

Over 70% of habitats of EU interest are reported to be negatively impacted by agriculture, mainly resulting from ecologically unsuitable grazing regimes and abandonment (NPWS, 2019). Pollution resulting from agricultural or forestry-related activities and household sewage systems, is a primary threat to habitats of EU interest (e.g., estuaries, coastal lagoons, and turloughs). Elevated nutrient concentrations (phosphorus and nitrogen) arising largely from agriculture and wastewater discharges to water from human settlements continues to be the most widespread water quality problem in Ireland (Environmental Protection Agency, 2016). Furthermore, there is evidence that climate change is negatively impacting Irish habitats, especially coastal and upland habitats (Gleeson *et al.*, 2013). Expected increases in temperature, changes in precipitation patterns, weather extremes (storms and flooding, sea surges, flash floods) and sea-level rise will affect the abundance and distribution of Irish species. These pressures and threats are likely to increase over the next decade unless substantial action is taken (*National Biodiversity Action Plan*, 2017). Therefore, it is critical that we not only act urgently to relieve threats and pressures on biodiversity, but also simultaneously act to mitigate climate change.

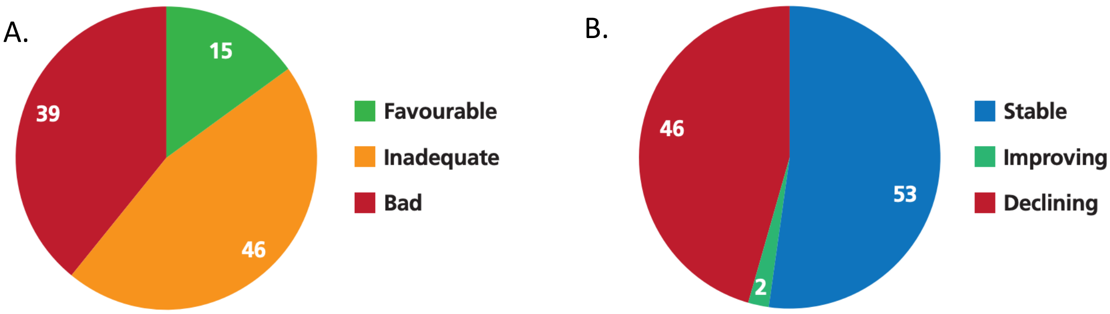

Figure 2. The Overall Status of habitats from Ireland's Article 17 Report (NPWS, 2019). This figure shows that 85% of habitats are in Unfavourable (i.e. Inadequate or Bad) status (Fig. 1A), with 46% of habitats demonstrating ongoing declining trends (Fig. 1B).

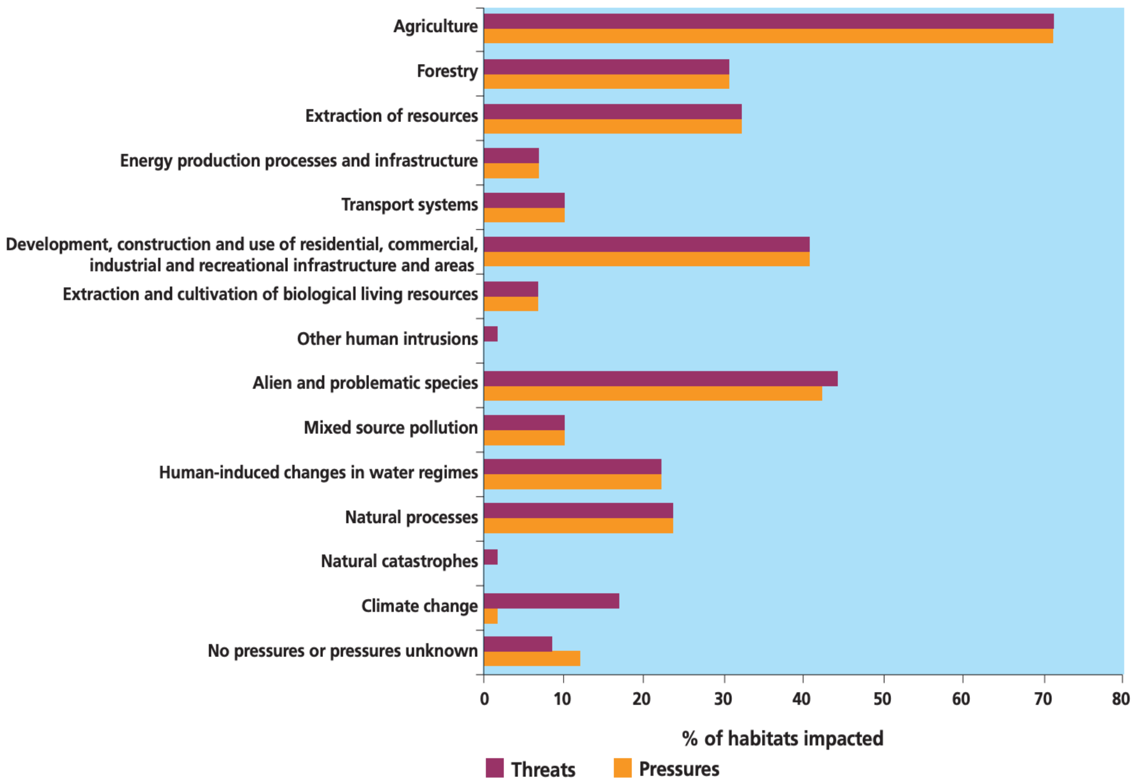

Figure 3. Percentage of habitats impacted by pressure and threat category from Ireland's Article 17 Report (NPWS, 2019).

2.3 Renewable energy and biodiversity

The goal for renewable electricity production in Ireland as outlined in the 2019 Climate Action Plan is to increase electricity generated from renewable sources from 30% to 70% by 2030. There are three primary life stages of renewable energy facilities with impacts on biodiversity: construction, operation and decommissioning (Table 2). We outline the main biodiversity impacts identified for each stage within four renewable energy sectors (offshore wind, onshore wind and solar, and bioenergy) and potential mitigation methods. We make recommendations for each renewable energy source and life cycle stage (Table 2).

General recommendations that cut across all renewable energy sectors include:

- Placing infrastructure in strategic locations to minimize negative impacts to sensitive areas and species; particularly with respect to Annex I habitats and Annex II species of the Habitats Directive and Annex I and II species from the Birds Directive.
- Renewable energy infrastructure can provide habitat for biodiversity if it represents a more biodiversity friendly land/sea use than the existing use. Biodiversity benefits of the change in land/sea-use can be maximised through appropriate design and management.
- Develop and follow a decommissioning plan for biodiversity protection and rehabilitation/restoration.

Table 2: Key biodiversity impacts common to the four main renewable energy methods (offshore wind, onshore wind, solar, and bioenergy) with recommendations on how to avoid, minimise, and mitigate potential negative impacts.

Life Cycle Stage	General potential impacts	Offshore wind	Onshore wind	Solar	Bioenergy
Construction	• Land-use change • Disturbance • Habitat fragmentation • Habitat loss	1. While individual wind farm footprints are low, consider the timing of development to minimise industry-wide impact during the construction of multiple wind farms. 2. Marine planning strategies such as the National Marine Planning Framework that explicitly include marine biodiversity protection and restoration are necessary. 3. Use existing sensitivity planning tools and develop new mapping tools to identify areas unsuitable for offshore wind in advance of construction. 4. Time construction to have the least possible overlap with important	1. New wind turbines (and repowering) should only be constructed in appropriate locations that do not compromise biodiversity or WFD obligations. 2. Avoid vulnerable and protected peatland and other nature protected areas. 3. Ensure that the site selection process and turbine placement is informed by the existing Special Areas of Conservations and Special Protected Areas, as well as the functional connectivity of isolated resources necessary for these protected sites. 4. Include migration pathways or commuting/foraging routes for key	1. Solar panels should be incorporated into existing built infrastructure 2. Farms of solar panels on agricultural or undeveloped land should be discouraged, because of the large areas of land required for their operation leading to direct impacts on biodiversity and indirect impacts through the displacement of other land-uses and intensification of semi-natural areas. 3. If utility-scale solar energy systems cannot be avoided, they should be strategically placed to avoid sensitive areas and minimize negative impacts on biodiversity.	1. Major land-use change should be avoided to minimise soil carbon losses (e.g., conversion of unimproved grassland to improved grassland or arable). 2. Avoid natural and semi-natural areas. 3. Prioritise the use of waste products for bioenergy.

		Cetacean migration, feeding, or breeding activities. 5. Investigate the potential to implement floating wind farm technology to minimise sea-bed disturbance. 6. Assess pile driving effects in key spawning ground for fish stocks and use exclusion zones to promote recovery of stocks. 7. Use existing technology to reduce the noise created by construction activities (e.g., air bubble curtains). 8. Associated onshore support infrastructure for offshore wind should be developed with sensitivity to biodiversity impacts. 9. Design offshore infrastructure to provide habitat for biodiversity (artificial reefs).	species in planning processes. 5. Co-locate wind with more intensive agricultural land uses.		

Operation	• Habitat displacement • Injuries to animals	1. If a wind farm must be constructed in an important bird migration pathway, alternative migration corridors between wind farms must be available. 2. Better monitoring systems should be developed to monitor risk and risk avoidance measures (e.g., temporary curtailment) should be implemented. 3. Maximise positive biodiversity impacts of wind farm associated fisheries exclusion zones.	1. Encourage energy-environment/PFES/community schemes to promote enhancement of biodiversity in wider local landscape. 2. Real-time/smart monitoring to inform strategic curtailment during times of high bat and bird activity. 3. Community engagement in local biodiversity enhancement schemes.	1. The functional use of land beneath panels should be promoted (e.g., low intensity grazing). 2. Alternatives to herbicide use to manage vegetation below and between solar panels should be developed and used. 3. Management for tolerant elements of biodiversity between, around and beneath solar panels	1. Mandate the protection of important biodiversity landscape features (hedgerows, ponds, buffer strips, woodland edges etc.)
Decommissioning	• Disturbance • After-care or rehabilitation of decommissioned sites	1. Maintain and upgrade the wind turbines as necessary to prevent or delay decommissioning. 2. Plan for decommissioning to maintain biodiversity benefits achieved through artificial reef formation	1. Maintain and upgrade the wind turbines as necessary to prevent decommissioning.		

2.4 Natural Capital Accounting and Nature-based Solutions

Biodiversity provides ecosystem services and numerous resources for human well-being. For example, wetlands provide water purification, sediment retention, habitat for species as well as cultural enjoyment and these services should be accounted for. If biodiversity is not protected, the ability of nature to provide these services will be reduced. An emerging approach is to think of biodiversity and the resources and services it provides (our natural capital) as an asset that needs to be maintained and managed. This Natural Capital Accounting approach is a systematic method to measure and report on stocks (biodiversity, soils, water, geology) and flows (ecosystem services and benefits) of natural capital. This quantification of the value of ecosystems, including their resources and services, can assist in making decisions that benefit the environment, society, and the economy. Given that the location, quantity and quality of natural capital stocks (including biodiversity) underpin GHG regulation in the atmosphere natural capital accounting methods are strongly recommended for assessment and planning of ecosystem service provision across a range of interlinked services provided by natural capital.

Current practices for natural resource exploitation are inefficient and unsustainable. These practices may produce an economic benefit in the short term, but longer-term economic growth is inherently hindered by unsustainable methods and their negative impacts on natural capital. By explicitly considering natural capital as underpinning economic activity and wellbeing Nature-based Solutions can be developed to restore and rehabilitate degraded ecosystems as a sustainable method of managing and leveraging our natural assets. Throughout this review we identify several Nature Based Solutions that would be potential win-wins for biodiversity and climate.

3. Offshore wind farms

There is a Climate Action Plan target of at least 3.5 GW of offshore renewable energy mainly produced by wind. The development of offshore wind farms will be shaped by the Offshore Renewable Energy Development Plan and aligned with the Marine Strategy Framework Directive. Seven offshore wind projects have been recently classified as “Relevant Projects” to expedite their development and will secure special status under the proposed Marine Planning and Development Management Bill. The approved Relevant Projects have the capacity to produce up to 3.8 GW of offshore wind energy and consist of six projects off the east coast of Ireland in the Irish Sea and one project off the west coast in the North Atlantic Ocean. Together these projects plan to add around 260 wind turbines to the Irish Sea and 20 turbines to the Atlantic Ocean. The total size of the developments amount to around 434 km^2 in the Irish Sea, and about 4 km^2 in the Atlantic Ocean. To put the scale of these developments into a broader perspective, all offshore development will cover approximately 0.0095% of the Irish Sea. Despite this relatively small footprint, there is potential for impacts on biodiversity.

3.1 Constructing offshore wind farms

The installation of new wind turbines often leads to the destruction and/or alteration of the seabed, which negatively impacts marine invertebrates and other species living on the seabed (Gill, 2005). Boulders are removed and the seabed is dredged to level it prior to installation and to provide trenching for the installation of cables that connect the offshore turbines to onshore substations. In the short-term, dredging increases turbidity which can negatively impact sea-bed organisms, filter-feeding invertebrates, and fish. In the long-term, these construction activities can compact the seabed and alter its morphology. There are potential negative effects of pile driving in key spawning grounds, both from the perspective of fish stocks of interest to humans, and through food chain effects on sea birds and other marine organisms (Perrow *et al.*, 2011).

However, negative impacts of offshore wind farm construction are generally considered to be minor by most European Environmental Impact Assessment (EIA) reports (Vaissière *et al.*, 2014) as the land needed for construction of wind turbines is considered negligible compared to the total size of the seabed. Additionally, evidence from previous EIA reports show that the seabed is recolonized by animals, algae and plants relatively rapidly after construction is completed (Leonhard & Pedersen, 2006; Lindeboom *et al.*, 2011; Vaissière *et al.*, 2014). Technology is currently being developed for floating wind farms, in which turbines are placed on floating platforms (e.g., Hywind Scotland Wind Farm; https://www.equinor.com/). Future plans for offshore wind farm construction could employ floating wind farm technology which would minimise negative impacts to the seabed.

Construction noise has been shown to negatively impact marine mammals (Madsen et al., 2006). Noise emissions from activities such as pile driving are loud enough that they could cause temporary or permanent hearing loss in animals like the Harbour Porpoise, (*Phocoena phocoena*), (Lucke *et al.*, 2009; Kastelein *et al.*, 2010) if exposed at close range. Harbour seals (*Phoca vitulina*) have also been found to avoid wind farms during the pile driving, but return to the area shortly (within two hours) after the activity is ceased (Russell *et al.*, 2016). The severity of these impacts is determined by the duration of the noise and the spatial dynamics of the marine mammal populations. Negative impacts can be minimized if animals are able to leave the immediate construction area throughout the duration of the pile driving activities. Several technologies exist to mitigate the noise emissions caused by construction activities such as noise reducing barriers (air bubble curtains) (Lucke *et al.*, 2011; Dähne *et al.*, 2017).

There are biodiversity considerations regarding the construction of onshore electrical infrastructure, such as substations. If placed inappropriately, they could disturb sensitive coastal or inland habitats and/or species. Environmentally sensitive areas should be avoided when determining the locations for these structures. These areas can be identified using existing technology such as sensitivity mapping tools (Burke, 2018).

Overall, negative impacts during the offshore construction phase should be short-term and there are several methods that can be used to mitigate negative effects on biodiversity. The use of "no take" exclusion zones around wind farms can mitigate negative effects in the short-term and promote long-term recovery of biodiversity stocks (Haggett *et al.*, 2020). Careful land and sea use planning using frameworks such as the National Marine Planning Framework (*National Marine Planning Framework*, 2021) are necessary to maximize potential positive impacts and minimize potential negative effects on biodiversity and climate.

3.2 Operation of offshore wind farms

Negative impacts on biodiversity during the operation stage will last for the entire lifespan of the wind turbine (~25 years). The primary concern relevant to Ireland are the impacts of wind turbines on seabirds, including collision mortality, habitat loss and displacement, and barrier effects (Cummins *et al.*, 2019). Consistent with these potential impacts, offshore wind farms generally have a negative impact on seabird abundance (Stewart *et al.*, 2007), and seabirds tend to avoid turbines during operation (Desholm & Kahlert, 2005; Petersen *et al.*, 2006), which could indirectly result in habitat loss through reduced areas for foraging. Turbines could also act as physical barriers that impact birds' abilities to migrate or forage (Larsen & Guillemette, 2007). Additionally, birds could collide with the turbines, though collisions are generally thought to result in minimal mortality of birds in a population (Drewitt & Langston, 2006).

Most negative impacts can be mitigated or minimised by avoiding placement of wind farms in areas with sensitive habitats and populations of key species. In Ireland, more site-specific information is needed, including the distribution of these key species, to accurately characterise the risk (Bowgen & Cook, 2018). Sensitivity mapping tools have been developed to identify areas of concern (Burke, 2018). It is especially important to avoid placing wind farms in areas important to seabird foraging and breeding. If sensitive areas cannot be avoided, an alternate solution would be to provide migration and foraging pathways between the wind farms by providing wide (several km) spaces free from turbines between wind farms (Wilhelmsson *et al.*, 2010; Goodale *et al.*, 2019; Krijgsveld). Regional planning of developments therefore needs to take the location and intensity of multiple wind farms into account.

Monitoring of seabird movements and occurrences prior to and during the construction and operation of offshore wind farms through GPS tagging, direct observation, and remote monitoring (acoustic, video, radar) techniques are needed to determine the potential for negative impacts and identify mitigation methods, including strategic curtailment of operations during times of high seabird activity (e.g., foraging or migration).

3.3 Decommissioning offshore wind farms

The decommissioning stage is an understudied component of offshore wind energy, however it is generally assumed that impacts will be similar to those in the construction stage (Gill, 2005; Vaissière *et al.*, 2014). Options include complete or partial removal of turbines (Deeney *et al.*, 2021). Complete removal would have similar impacts as the construction phase and could have negative impacts on biodiversity as the plants and animals that colonized the turbine foundations would be destroyed (Gill, 2005; Vaissière *et al.*, 2014). A solution to this might be the partial removal of turbines that leaves the foundations intact. This would preserve the biodiversity that accumulated on the underwater structures. However, this would result in permanent fixtures on the seafloor and potential obstacles to shipping and fishing. An alternative is that the turbines could be continually maintained and upgraded as needed, so that removal is not necessary. Regardless, decommissioning plans should be drafted and continually updated as new technology becomes available and any decommissioning plans should consider potential impacts on biodiversity.

3.4 Offshore wind farm opportunities for biodiversity protection & restoration:

With careful design, development of offshore wind farms can have several positive impacts on marine biodiversity (Inger *et al.*, 2009). Wind turbines and scour protection structures provide habitat and protection for marine wildlife such as fish and invertebrates (Leonhard & Pedersen, 2006; Wilhelmsson *et al.*, 2006). Long-term studies from Denmark have shown that fish species abundance and diversity increased near turbines (Stenberg *et al.*, 2015). Wind farms can be strategically located to protect areas that suffer from overfishing, as wind farms provide a barrier to fishing boats and trawlers.

3.5 Offshore wind farm research gaps:

- Negative impacts on seabird foraging (especially long-term impacts for key species)
- Biodiversity impacts of decommissioning
- Optimal artificial reef construction
- Impacts on migration pathways for birds and Cetaceans and assessment of alternative migration pathways.

4. Onshore wind farms

Onshore wind is currently the main renewable energy source in Ireland, with an installed capacity of 4.3 GW, with a planned increase to 8.2GW by 2030. However, wind farms can have negative impacts on biodiversity (Schuster *et al.*, 2015), and there are important biodiversity considerations when placing new wind turbines as well as managing and repowering existing wind farms. Appropriate siting of wind farms and early mitigation of key impacts during the construction stage have the greatest potential to reduce negative effects on biodiversity.

4.1 Constructing onshore wind farms

Wind farms are not as land intensive as some other sources of renewable energy (e.g., bioenergy), but they still require that land be acquired for their placement. Determining the appropriate placement of wind farms (i.e., siting) is critical for avoiding the worst negative impacts. For example, inappropriate siting of a wind farm and failure to perform an EIA led to a major peat slide in county Galway in 2003, which impacted terrestrial and aquatic ecosystems and cost Ireland over €5m in fines. Therefore, it is essential that wind farms and associated infrastructure, such as service roads, are placed in appropriate locations to avoid both direct and indirect impacts on biodiversity and water quality and that EIAs consider environmental risks such as peat slides to avoid future occurrences. This includes avoiding placement of wind turbines on deep and/or vulnerable peat soils. To be effective, wind turbines must be sited in areas where average wind speeds are high. This often leads to proposed sites in upland areas that can overlap with important habitats for birds (Drewitt & Langston, 2006).

Potential biodiversity impacts of onshore wind turbines, and associated infrastructure such as service roads and buildings, include: vegetation disturbance, habitat loss, and habitat fragmentation. Construction of wind farms requires land to be cleared for infrastructure installation and ongoing servicing and vegetation such as trees to be removed (van Haaren & Fthenakis, 2011). If trees are cleared from natural forests, other species of plants and animals can also be lost. Grid connections require further development of land surrounding the wind farm.

4.2 Operation of onshore wind farms

The potential impacts during the operation phase are likely less severe than those caused by the construction phase (Pearce-Higgins *et al.*, 2012). The primary concerns are negative impacts to birds and bats, which are disproportionately affected by windfarms (Schuster *et al.*, 2015; Rydell *et al.*, 2017; Laranjeiro *et al.*, 2018). Impacts include habitat loss and/or fragmentation, displacement from feeding or nesting areas, and injuries (including barotrauma and collisions) from turbines. Direct collisions are of particular concern as they can result in lethal and sublethal injuries affecting population viability (Grodsky *et al.*, 2011). Bats are particularly vulnerable to fatality due to collisions (Schuster *et al.*, 2015; Rydell *et al.*, 2017), however the reasons for this are still poorly understood (Cryan & Barclay, 2009). In North America, the risk of bat collisions has been shown to be strongly influenced by weather (Arnett *et al.*, 2008; Baerwald & Barclay, 2011), indicating that curtailing wind farm operation during certain weather conditions could potentially prevent some fatalities. However, research is needed to determine if these associations exist in Ireland. Additionally, turbine placement has some influence on fatality risk, as the highest fatality rates are generally attributed to turbines located at the ends of turbine strings (Arnett *et al.*, 2008). Ireland has nine species of bats, all of which are protected under the Wildlife Act 1976 and subsequent amendments and Annex IV of the Habitats Directive. Three of these, the common pipistrelle (*Pipistrellus pipistrellus*), soprano pipistrelle (*Pipistrellus pygmaeus*) and Leisler's bat (*Nyctalus leisleri*) are considered high risk in relation to turbines, based on research from the UK and Europe (EUROBATS, 2014; Mathews *et al.*, 2016). Ireland's population of Leisler's bats are considered internationally important as Ireland is a stronghold for the species, constituting 20-25% of the global population (Marnell *et al.*, 2009).

It is important to obtain damage estimates from all levels of wind farm operation to mitigate negative impacts on-site and to inform future development. To make appropriate recommendations for bats, it is necessary to obtain estimates of the number of fatalities per turbine and per wind farm, so that cumulative, industry-wide, damage to their populations can be calculated. Total national population estimates should be continuously updated based on the results of action-based monitoring. The current practice is to apply a similar logic and calculation as that used for impacts to birds, through the implementation of the EIA directive. As supported by Rushe & Anor V an Bord Pleanala [2020] IEHC 122 case law, the permissible threshold for species decline is up to a 2% total population (nationwide) loss of birds from negative impacts of a wind farm development for the threshold of 'significant impact'. Attempts have been made to apply this logic to bats, despite them having very different life histories from birds (generally lower population recovery potential) (Healy *et al.*, 2014, 2019). Bats have a considerably slower life history strategy and are therefore less capable of recovery from perturbation; furthermore, they are ecosystem engineers and provide an invaluable role to ecosystem stability and function. Therefore, effort is needed to identify impact threshold limits which are appropriate for this taxonomic group.

Birds are vulnerable to habitat loss, displacement, and increased mortality due to collisions. In Ireland, the Hen Harrier (*Circus cyaneus*) is a particular species of concern. Hen harriers are raptors that live and breed in upland areas that often overlap with existing and potential wind farms (Fernández-Bellon *et al.*, 2015). This species is listed on Annex 1 of the EU Birds Directive, so Ireland is responsible for maintaining its favourable conservation status. More research specific to the Hen Harrier in Ireland should be conducted to understand whether this habitat overlap leads to negative impacts, such as habitat displacement, collisions or reduction in prey species. Generally, bird mortality has been found to be relatively low due to collisions with wind turbines (Drewitt & Langston, 2006; Lucas *et al.*, 2008), however long-term, active monitoring is needed to determine whether these low mortality rates are more significant for long-lived species with slow maturation and low reproductive rates, such as raptors. Studies of the interactions between raptors and wind farms outside of Ireland have found that raptor abundance decreased 47% after the construction of wind turbines (Garvin *et al.*, 2011), and that raptors often demonstrate avoidance behaviours at wind farms that could lead to habitat loss via displacement (Garvin *et al.*, 2011; May, 2015; Dohm *et al.*, 2019). There is some evidence that these negative impacts are diminished over longer time scales (Dohm *et al.*, 2019). It is also possible that the Hen Harrier could be negatively impacted by a reduction in available prey species due to wind farms (Fernández-Bellon *et al.*, 2019), further indicating the need for active monitoring of prey populations and associated habitat management throughout the lifespan of wind farms.

Careful planning of appropriate site location is considered to be the most important method for mitigating negative impacts on birds and bats (Hötker *et al.*, 2005). For example, sites in areas with high occurrence rates of raptors, such as the Hen Harrier, should be avoided as wind farm sites (Hötker *et al.*, 2005). Mortality due to collisions could potentially be lessened through modifications in turbine design, placement, and operation (Dai *et al.*, 2015). Turbine height and placement have a significant impact on collision risk, with taller turbines and turbines at higher elevations resulting in higher collision mortality (Lucas *et al.*, 2008). Strategic arrangement of turbines within the sites can further reduce negative impacts (Drewitt & Langston, 2006).

Impacts to birds and bats could be potentially mitigated during operations; however, these are less well developed. Temporary curtailment of turbines during high-risk conditions for bat and bird collisions may help to reduce fatalities (Lagrange *et al.*, 2013; Arnett & May, 2016; Smallwood & Bell, 2020) without compromising turbine performance and energy output (Rogers, 2020). However, research is needed to demonstrate the efficacy of curtailment in an Irish context.

4.3 Decommissioning onshore wind farms

In the decommissioning phase, similar disturbances as found in the construction stage can be expected if the turbines are removed. Extending the lifespan of turbines through retrofitting and repowering can also minimise displaced construction impacts at new sites.

Repowering can present challenges however, as sites which were previously licensed are may subsequently be recognised as unsuitable, due to biodiversity and habitat impacts. Active habitat restoration and/or rehabilitation may be needed to mitigate negative biodiversity impacts of decommissioning.

4.4 Onshore wind farm opportunities for biodiversity protection & restoration

When implemented appropriately, the development of onshore wind presents opportunities for biodiversity restoration and protection. Areas surrounding the wind turbines can be rehabilitated into natural habitats. Many of these areas were previously functioning as carbon sinks that help regulate climate (i.e., peatlands) and have the potential to provide habitat for hundreds of plant and animal species. For example, the Mountlucas rehabilitated cutover bog in Co Offaly provides habitat for a diversity of plant and animal species, including seven species of orchid and six red-listed bird species (*Mountlucas Bog Cutaway Bog Decommissioning and Rehabilitation Plan*, 2021). The ecological potential of each site will vary according to its natural state, level of degradation, and constraints on biodiversity imposed by the wind turbine operation, therefore more research is needed to determine the best rehabilitation and management practices for these sites. However, rehabilitating degraded habitats can be done in a way to not only promote biodiversity, but also provide considerable co-benefits for climate and water quality.

Wind farms could be co-located with areas already under intense land-use, such as agriculture or forestry. Approximately 12-20 hectares are needed to place a wind turbine, but the turbine itself occupies less than 0.5 hectares on average. Farmers or foresters can generally continue to use around 95% of the land to plant crops or graze livestock near the turbine. The siting of wind farms in areas with lower levels of biodiversity would remove some conflicts arising from inappropriate siting. Land prices, availability of wind energy, and willingness of landowners/managers to support wind farm installations on land with higher productivity value may present challenges. There are opportunities to develop payment for ecosystem services/energy-environment schemes, to encourage landowners from whom land is leased and local communities to manage their surrounding land in a more biodiversity friendly way, perhaps though leveraging a portion of the community benefit funds towards such schemes.

4.5 Research gaps for onshore wind farms:

- Mortality of Irish bat species in relation to wind farms; particularly with respect to population dynamic sensitivities and thresholds
- New sensors and monitoring methods (including acoustic, radar and video monitoring) for impacts and testing effects of mitigation measures.
- Testing curtailment of wind farm operation during weather associated with high mortality and/or during times of high bird and bat activity.
- Understanding the ecological potential for natural sites to be rehabilitated
- Hydrology impacts of rehabilitating wetlands (blocking drains, etc.)
- How to promote equity and just transition for community buy in to climate mitigation and biodiversity conservation
- Cumulative damage estimates at all levels to enable population-wide impacts to be assessed (i.e., turbine level, wind farm level, and industry level)

5. Solar photovoltaics (PV)

The 2019 Climate Action Plan includes increasing energy produced via solar photovoltaics (PV) to 1.5 GW of installed capacity by 2030 from a relatively low base of 24.2 MW in 2018 (SEAI, 2020). A fundamental consideration for the expansion of PV energy in Ireland should be scale. The scale of PV installations varies greatly, from distributed solar energy systems installed on rooftops of residential houses or commercial buildings, to utility-scale solar energy systems that occupy large areas of land. Distributed solar energy systems are relatively small in capacity (< 1 megawatt [MW]) and are generally built into existing infrastructure, where they are likely to have negligible adverse impacts on biodiversity (Dale et al., 2011). Therefore, initiatives such as the micro-generation grant scheme for PV designed to promote the installation of solar panels on individual homes (*Climate Action Plan*, 2019) should continue to be developed and supported. However, utility-scale solar energy systems are large-scale, high-capacity (> 1 MW) operations that have far greater potential to cause negative impacts on biodiversity. It is estimated that current PV technology requires about 1.5-3 hectares of land per MW of electricity production (Walston *et al.*, 2016; Kosciuch *et al.*, 2020). According to these estimates, if Ireland was to employ only utility-scale solar energy facilities to reach their Climate Action Plan target of 1.5 GW of capacity, a minimum of 2,250 hectares of land would be needed (for perspective, a rugby field is about one hectare, or it represents a quarter of all land used to grow potatoes in Ireland). The large land area requirements of solar PV have many potentially negative impacts on biodiversity (Macknick *et al.*, 2013; Hernandez *et al.*, 2014), including key impacts such as habitat loss and fragmentation. Large scale habitat loss has consistent negative impacts on biodiversity (Fahrig, 2003) and is a primary threat to biodiversity globally and in Ireland (*National Biodiversity Action Plan*, 2017; Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, 2018).

5.1 Construction of solar PV farms

The construction of utility-scale solar facilities requires the conversion of existing agricultural areas to solar farms, or the development of additional land. There are potentially negative consequences for biodiversity for either of these land-use options since land-use change to more intensive uses generally has negative impacts on biodiversity (Newbold *et al.*, 2015). The conversion of existing agricultural land to solar farms could displace previous agricultural activity to less intensively farmed or semi-natural areas (Hernandez *et al.*, 2014), with negative consequences for native plants and animals through resulting habitat loss and fragmentation (Fahrig, 2003; Hernandez *et al.*, 2015b). The negative impacts of habitat loss and fragmentation are potentially further exacerbated during the construction of transmission lines and corridors (Andrews, 1990).

Siting solar facilities in areas already degraded and/or developed by humans (i.e., the built environment) can reduce the magnitude of adverse impacts (Hernandez *et al.*, 2015a). Outside of the built environment care must be taken so that land use change, habitat loss, and habitat fragmentation are minimized and that solar farms are not placed in sensitive areas or areas acting as carbon sinks as solar panels reduce productivity through light and rainfall interception (e.g., peatlands and semi-natural grasslands in Ireland) (Hernandez *et al.*, 2014, 2015a).

Construction of utility-scale solar energy systems requires land development, including clearing the existing vegetation and grading the soil (Macknick *et al.*, 2013), leading to direct environmental impacts such as soil disturbance, habitat loss, degradation, and fragmentation (Macknick *et al.*, 2013; Hernandez *et al.*, 2014). Construction can have indirect impacts such as changes in water quality due to soil erosion, herbicide application and facilitating the spread of invasive species.

Some negative impacts of solar PV installation could potentially be mitigated through actions such as the promotion of functional land use beneath the panels and maintaining natural habitat within the landscape matrix. For example, planting native plant species which can tolerate the altered conditions beneath and between solar panels to create habitat for pollinators (Graham *et al.*, 2021). However, direct and indirect habitat loss is much more difficult to mitigate. Some habitat loss could potentially be mitigated through compensation by rehabilitating natural areas elsewhere, however this kind of offsetting should only be considered as a last-resort (Simmonds *et al.*, 2020).

5.2 Operation of solar PV farms

The potential negative impacts of utility-scale solar facilities on biodiversity are significant during the operation stage (Hernandez *et al.*, 2014). Land developed for built infrastructure during the construction stage remains unusable to wildlife throughout the lifespan of the facility (Tsoutsos *et al.*, 2005). The installation of solar panels alters the composition of plant species that can colonize and persist in solar farms, as they reduce the amount of available light and water and influence microclimate. Arrays of solar panels can also cause seasonal and diurnal variation in air and soil microclimate that could scale up to affect plant-soil processes and carbon cycling (Armstrong *et al.*, 2014, 2016). Both above-ground plant biomass and plant species diversity are lower under solar panels, and these differences can be explained by variation in microclimate and vegetation management (Armstrong *et al.*, 2016).

Facilities regularly apply herbicide during the operation stage to prevent the regrowth of vegetation that was cleared during construction to avoid shading of the panels, pests, and reduce the risk of fires (Macknick *et al.*, 2013). There are several potential negative impacts associated with regular herbicide use, including off-target effects in wild plant communities (Russo *et al.*, 2020), detrimental effects on pollinators (Cullen *et al.*, 2019; Zioga *et al.*, 2020) and water pollution (Abbasi & Abbasi, 2000). There are also concerns that these systems could generate even more problematic water pollutants as several toxicants are used in the operation and maintenance, including coolants, antifreeze, and rust inhibitors (Abbasi & Abbasi, 2000; Tsoutsos *et al.*, 2005). The panels themselves contain toxic heavy metals, such as cadmium sulphide, that could potentially leach from the panels (Abbasi & Abbasi, 2000).

It is possible that birds could collide with solar panels. However, previous work found that mortality due to collisions was negligible compared to total population sizes (McCrary *et al.*, 1986, Mojave Desert). Furthermore, the impacts of utility-scale solar energy facilities on avian mortality in the United States are estimated to be similar to those in the wind energy sector (Walston *et al.*, 2016). However, as the development of utility-scale solar is in its infancy in Ireland, more work is needed to be able to accurately predict the effects of these facilities on Irish birds. It seems likely that the habitat modification effects of solar would have a more significant effect on bird populations than collision effects.

5.3 Decommissioning solar PV farms

The primary impact of concern during the decommissioning stage would be pollution of the environment with toxic materials contained within the solar cells due to damaged cells or improper recycling (Fthenakis *et al.*, 1984). However, these risks can be almost entirely prevented by following waste handling regulations (Fthenakis, 2000).

5.4 Research gaps for solar PV:

- Impacts of PV systems on native bird populations
- Determine what kinds of functional ecosystems can be established in and persist in Ireland under solar panels with minimal chemical use

6. Biofuel cultivation

There is a need for sources of sustainable fuel, such as aviation in the medium term and home heating and cooking, and road vehicle fuel in the short term, with electrification of the heating and terrestrial transport sectors likely to largely displace biofuels in these sectors in the medium term. The 2019 Climate Action Plan aims to set a target for biogas and biomethane development and to develop and stabilise the indigenous supply of biomass for renewable heat and combined heat and power. However, the development of bioenergy could have significant negative impacts on biodiversity. The primary concerns in Ireland are that the cultivation of bioenergy crops and creation of biomass plantations are land-use intensive and will require a significant amount of water (Fritsche *et al.*, 2010; Beringer *et al.*, 2011). These land-use and water-use requirements have the potential to compromise our existing obligations to N2000 and WFD. It should be noted that agricultural land use, with associated habitat destruction and nutrient leaching, is currently the most prevalent threat to habitats, species and freshwater quality in Ireland (NPWS, 2019). It is likely that expansion or intensification of agricultural land use through biofuel cultivation will further threaten biodiversity.

Biogas and biomethane are emerging technologies that could be used as a climate mitigation strategy in Ireland. Biogas is produced from the decomposition of organic waste materials (i.e., feedstocks) such as animal manure, sewage sludge, and food waste (Achinas *et al.*, 2017). These waste products are placed in a digester system that takes advantage of naturally occurring anaerobic digestion to break down the waste and produce gases, such as methane. This process produces a renewable biogas that can be used for a variety of applications such as producing heat and power (Achinas *et al.*, 2017). The biogas can be further refined into biomethane, which can then be injected into natural gas pipelines or used to fuel vehicles. In the Climate Action Plan, biogas is classed as an emerging technology with need for targets for production to be set according to feedstock supply issues. However, it is also the most expensive in terms of the Marginal Abatement Cost Curve (*Climate Action Plan*, 2019).

6.1 Conversion of land use to biofuel crops

Of renewable energy sources, the biomass cycle requires the greatest amount of land (Fthenakis & Kim, 2009). In Ireland, this would require that existing agricultural land be converted to produce bioenergy crops, or that additional land be developed for agriculture. Either option would bring significant land-use changes, which generally expedites biodiversity loss (Sala *et al.*, 2000; Newbold *et al.*, 2015; Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, 2018). Negative biodiversity impacts are generally expected when natural and semi-natural areas (e.g., unimproved semi-natural grasslands) are converted to biomass plantations.

Several lines of evidence indicate that bioenergy has potential to be poorly implemented, leading to this sector directly and indirectly producing more greenhouse gas emissions than traditional fossil fuels (Searchinger *et al.*, 2009). The conversion of carbon rich ecosystems (e.g., tropical forests or peatlands) into biomass plantations leads to the release of that previously sequestered carbon into the atmosphere, resulting in a carbon debt that could take >100 years to pay back (Searchinger *et al.*, 2008; Gibbs *et al.*, 2008). The production of bioenergy crops could lead to increases in greenhouse gas emissions via land-use change, as bioenergy plantations often displace agriculture into natural habitats such as forests and grasslands (both locally and internationally) (Searchinger *et al.*, 2008, 2015). Farmers may attempt to replace agricultural land lost to biofuel by increasing the yields from remaining croplands, leading to increased usage of water and fertilizer (Searchinger *et al.*, 2008, 2015).

In Ireland, it has been suggested that grass be used as a feedstock for biomethane (Smyth *et al.*, 2009). There are several advantages of using grass as a feedstock in Ireland. For example, arable land is not needed for growing grass and farmers are already familiar with growing it as over 90% of Ireland's agricultural land is under grass (Smyth *et al.*, 2009). If livestock production systems are disincentivised due to their high methane production to meet Climate Action Plan targets for the agricultural sector, then alternative land uses for former pasture will need consideration. However, there are potential biodiversity impacts of grass to biomethane systems. The main concern is that the higher value of crops due to waste valorisation may drive further land-use change and intensification.

6.2 Operation of biofuel cropping

The cultivation of bioenergy crops, as with other intensively farmed arable crops, can negatively impact soil by increasing erosion, reducing soil organic carbon and therefore decreasing soil fertility. Soil organic carbon is an important indicator of soil quality and productivity, with higher values corresponding to better soil water retention, higher soil biodiversity, and higher productivity. Soils are also important carbon sinks, as the soil organic carbon is sequestered instead of being released into the atmosphere. There are three main ways that the cultivation of energy crops can negatively impact soils— land use change, tillage, and residue removal (Wu *et al.*, 2018). For example, the initial conversion of undisturbed soil to tilled can result in 20-40% loss of soil carbon during the first 5-20 years of cultivation (Davidson & Ackerman, 1993). Furthermore, harvesting crop residues (i.e., dead plant material left after harvesting) can lead to soil erosion, have negative impacts on soil fertility, and reduce soil carbon, resulting in carbon dioxide emissions (Liska *et al.*, 2014). Some of these negative impacts could potentially be mitigated by locating bioenergy crops in areas with already degraded soils and using conservation tillage practices that leave a percentage of crop residues in place to be broken down naturally (Hoekman *et al.*, 2018). More research is needed to determine the best practices for bioenergy cultivation in Ireland.

The impacts of bioenergy crop cultivation vary in type, magnitude and scale, depend on the crop grown, and are difficult to generalize. For example, responses to bioenergy crops differ among pollinator taxa (Stanley & Stout, 2013). Moreover, effects on species vary depending on which crops were replaced by bioenergy crops (Stanley & Stout, 2013). Further research on taxa and landscapes specific to Ireland is clearly needed to better understand how the development of bioenergy through different land use changes could impact local biodiversity. Due to the large areas of land that would be required for Ireland to meet its energy production targets via biofuel, the spatial layout and distribution of such areas would largely influence the extent of negative impacts (Dauber *et al.*, 2010).

Bioenergy crop cultivation can negatively impact freshwater ecosystems through altering the magnitude and/or water quality of runoff (Cibin *et al.*, 2016). Furthermore, the cultivation of bioenergy crops can increase the amount of water withdrawn for agriculture (Beringer *et al.*, 2011; Hejazi *et al.*, 2014; Bonsch *et al.*, 2014; Chaturvedi *et al.*, 2015), which can have severe negative consequences for freshwater ecosystems (Dudgeon *et al.*, 2006). Increased fertilization due to bioenergy crops could also negatively impact freshwater environments (Carpenter *et al.*, 1998).

Additionally, the optimization of biomethane production from grass would likely require the inputs of fertilizer, herbicide, and lime to agricultural fields (Smyth *et al.*, 2009). These inputs could negatively impact native plants and animals, and result in detrimental impacts to aquatic ecosystems and groundwater (Abbasi & Abbasi, 2000). More research is needed on the quality of the grass products for biomethane production (e.g., single species versus multi-species swards) and sustainable management practices that avoid fertilizer and pesticide use. Some negative impacts could be potentially mitigated by incorporating the protection of important biodiversity landscape features, such as hedgerows, ponds, and buffer strips, into plans to expand the development of bioenergy in Ireland.

6.3 Biofuel Opportunities for biodiversity protection & restoration

The development of bioenergy in Ireland provides some opportunities for biodiversity protection and restoration. For instance, the development of this sector in Ireland may generate further pressure to develop innovative methods for sustainable agriculture, which could be beneficial for other renewable energy projects as well. Additionally, there is the possibility of incorporating biodiversity landscape features into bioenergy land uses, which should generally be encouraged.

6.4 Research gaps for biofuel cultivation:

- Predictions/modelling for the potential scale of bioenergy in Ireland without damaging biodiversity
- More research is needed on Irish specific taxa and their responses to bioenergy cultivation
- Land use planning is needed to prevent displacement of agriculture to natural or semi-natural areas
- Need more research on the quality of the grass product (single species or multi-species swards) in relation to suitability for biomethane and intensive management potentially needed (i.e., avoidance of fertilisers and pesticides)

7. Impacts of afforestation on water quality and biodiversity

7.1 Afforestation through plantations, woodland restoration, hedgerow retention, management and expansion

Reforestation of degraded forests and afforestation of previously cleared areas are necessary to meet our climate mitigation targets, as forests can slow the accumulation of greenhouse gas emissions by sequestering carbon (Rudel *et al.*, 2005). In addition to the short-term carbon sequestered during tree growth, there is also the potential for long-term carbon storage in urban structures by replacing carbon-intensive materials such as concrete and steel with engineered timber (Churkina *et al.*, 2020). Reforestation and afforestation are also considered to be relatively cost-effective climate mitigation strategies (Fuss *et al.*, 2018). The Climate Action Plan aims to plant 8,000 hectares of new forest each year to reach an ultimate target of 18% cover by 2046 (*Climate Action Plan*, 2019). If the right kinds of trees are planted in the right areas this afforestation target could have substantial positive impacts on biodiversity and water quality, however implementation is key to maximizing these positive effects (Allen & Chapman, 2001; Sacco *et al.*, 2021).

Like other climate mitigation methods, siting is critical for increasing the positive biodiversity impacts of afforestation and minimizing the potential negative impacts (Sacco *et al.*, 2021). For example, afforestation of naturally open areas of high biodiversity value (e.g., peatlands and semi-natural grasslands in Ireland) could have adverse impacts on the ecosystem and potentially result in the loss of distinctive species (Wilson *et al.*, 2014; Abreu *et al.*, 2017). In Ireland, the Hen Harrier is a sensitive species that has already experienced habitat loss due to afforestation of large areas of natural open habitat (O'Leary *et al.*, 2000). Current afforestation is heavily weighted towards monocultures of non-native species harvested for timber use with short usage lifespans which has limited value for both climate change mitigation and biodiversity. There are plans to continue to afforest areas of open habitat in Ireland with commercial non-native species, which would likely cause further damage to Hen Harrier habitat with limited positive biodiversity impacts. Rehabilitating and restoring degraded forests to natural and semi-natural states would be much more effective for conserving biodiversity while also contributing to climate mitigation targets.

It is estimated that about a third of the peatlands are drained for forestry in Ireland. Several of these sites have resulted in low-productivity forests, or failed plantations on deep peat and heathland slopes. In addition to ceasing afforestation efforts in peat habitats, restoration of these areas where possible would benefit both biodiversity and climate by reducing soil carbon emissions and promoting native biodiversity. Some work has been carried out on restoring peatlands post-felling of conifer plantations in Ireland and the UK, and this work should be supported and monitored to set realistic targets based on restoration trials (Andersen *et al.*, 2017).

When sited appropriately, it is also important to consider the species that will be used for afforestation. Native Irish forests consist of mixed deciduous tree species. However, many current afforestation schemes plan to plant monocultures of commercial, non-native, coniferous trees, such as Sitka Spruce. A wide body of evidence shows that monocultures provide limited biodiversity value (Altieri, 1999; Felton *et al.*, 2010; Iezzi *et al.*, 2018) and their effectiveness at sequestering carbon over long timescales has been questioned (Körner, 2017; Lewis *et al.*, 2019). Commercial monocultures may be effective at carbon sequestration in temperate environments (Forster *et al.*, 2021), such as Ireland. This research, however, ignores potential impacts on biodiversity. Furthermore, monocultures are more vulnerable to natural disasters (e.g., pest outbreaks, fire, and disease) than mixed forests (Verheyen *et al.*, 2016), which makes them risky as a carbon storage mechanism. Alternatively, forests composed of native mixtures have a high capacity to promote biodiversity through creating habitat for wildlife and attracting pollinators and seed-dispersing animals (Sacco *et al.*, 2021) and are more resilient to natural disasters. The resilience of forests to natural disasters is an important consideration for both climate mitigation and biodiversity. To maximize the chance of future resilience, it is important to not only plant a diversity of species, but also to identify genotypes and species that might be particularly robust to threats and/or changing climatic conditions. For example, common ash trees (*Fraxinus excelsior*) in Ireland are threatened by a potentially fatal, invasive fungal pathogen (ash dieback). Some genotypes of ash are naturally resistant to this disease, and Teagasc has been establishing a collection of these tolerant genotypes (currently over 200), which will undoubtedly benefit the resilience of ash in Ireland. A balance of commercial monocultures and mixed native forests could be a reasonable bet hedging strategy for climate mitigation and biodiversity. However, afforestation efforts would have the greatest positive impact on biodiversity if a mix of native trees were used (Lewis *et al.*, 2019; Sacco *et al.*, 2021).

The species used in afforestation projects also impact the surrounding environment, including freshwater ecosystems. For example, afforestation can have an acidifying effect on streams, largely due to the abilities of forest canopies to act as 'pollutant scavengers' (i.e., they enhance the capture of acidic pollutants such as nitrogen and sulphur). Coniferous trees, such as Sitka Spruce, are particularly problematic as they are efficient pollutant scavengers and also form an acid litter layer (Department of the Environment, 1991; Nisbet & Evans, 2014). This is especially harmful in "acid-sensitive" areas where the natural geology (e.g., shale, granite, and sandstone) already has an acidifying effect on streams (Collier & Farrell, 2007). Such areas are common in Ireland, and commercial coniferous plantations have the potential to exacerbate existing water quality issues, which could compromise our obligations to improve water quality via the WFD.

There are also concerns that increased afforestation could lead to a higher frequency of forest fires that would damage biodiversity and release carbon into the atmosphere. This could happen for several reasons. For example, if wetland areas (e.g., peatlands) that have a naturally low risk of fire are afforested, trees can dry up the wetlands via transpiration and increase the risk of fire in previously wet habitats. Commercial monocultures are particularly at risk for severe fires (Odion *et al.*, 2004), highlighting another advantage of planting native mixtures. Current Common Agricultural Policy rules incentivise the removal of scrub (e.g., gorse and heather) to keep land in good agricultural condition for eligibility of farm payments. This leads to fires being set to clear land and these fires can get into forests, lead to the erosion of peat soils, and release carbon. It would be beneficial for biodiversity and climate mitigation if the Common Agricultural Policy rules could be adapted and enforced to protect sensitive habitats from fire and provide for buffers around at-risk sites (i.e., disincentivise the clearance of land with biodiversity value). Buffer areas might also function as corridors for native plants and animals that could promote biodiversity (Altieri, 1999).

Hedgerows and other woodland habitats are an important part of the Irish agricultural landscape accounting for *ca.* 5% of the area of intensive farms (Larkin *et al.*, 2019) and up to 11% on extensive farms (Rotchés-Ribalta *et al.*, 2021), thus providing a valuable ecological network and habitat in the agricultural landscape. The ecosystem services delivered by hedgerows include carbon sequestration and storage, pollutant remediation, shelter for livestock and aesthetic appreciation of the landscape. Given the large areas under hedgerow, treelines, woodland copses, and scrub, the carbon storage and sequestration ecosystem services at a national scale are substantial. Hedgerows have annual carbon sequestration estimates of 0.5-2.7 tCO_2/ha/yr (Black *et al.*, 2014; Green *et al.*, 2019). The carbon estimated to be stored in hedgerows and woody habitats represents a significant store of carbon at the national scale that needs to be appropriately managed to ensure the stored carbon is not released back into the atmosphere.

More research is needed to assess whether hedgerow management is an effective land-use mitigation strategy (Green *et al.*, 2019). Resolving this uncertainty is a priority as the potential for hedgerows and woodlands on agricultural land to be an effective mitigation strategy is high. Teagasc have launched the Signpost Farm programme, which includes plans to conduct LiDAR surveys for 100 representative farms around the country (see link). Data from these LiDAR surveys can be used to quantify the carbon sequestration of hedgerows. Currently it is envisaged that surveys will take place at the beginning and end of the project, yet annual surveys throughout the lifetime of the project would generate the most useful data. We recommend the Signpost programme puts further resources towards estimating carbon sequestration in woodland, hedgerow, and scrub farmland habitats to build certainty.

7.2 Afforestation opportunities for biodiversity protection & restoration

In addition to afforestation, there is high potential for agroforestry (i.e., the intentional integration of trees and shrubs into crop and animal farming systems) to provide climate and biodiversity benefits in Ireland. The goal of agroforestry is to combine agriculture and forestry in a mutually beneficial way. Agroforestry can increase landscape diversity and promote biodiversity. Additionally, it has positive benefits for water, as it provides for land drainage through increased transpiration, prevents nutrient runoff, and reduces sedimentation of aquatic systems near farms. Agroforestry can also have positive impacts on livestock, by providing shade and shelter from rain and wind. Agroforestry can increase soil health by enriching soil organic carbon, improving soil nutrient availability and soil fertility, and promoting soil microbial diversity and activity (Dollinger & Jose, 2018). It can also increase the availability of foraging resources and habitat for wild bees (Kay et al., 2020). This indicates that incorporating flowering trees into grassland agriculture could promote pollinator diversity and enhance pollination services available in agroforestry systems. However, the implementation of agroforestry is key for optimizing the positive biodiversity benefits. The use of native trees in agroforestry practices should be encouraged, together with tree plants to increase landscape connectivity and act as buffers along riparian margins.

Hedgerows and woody habitats on farmland represent a vital ecological network supporting biodiversity in the agricultural landscape. Meeting the EU’s 2030 Biodiversity Strategy‘s target of 10% of farmland area being ‘high diversity landscape features’ would thus represent a protection of existing biodiversity, restoration of biodiversity on intensive farms where habitat cover tends to be in the single digits and an increase in the sequestration and carbon storage associated with hedgerows and woody farmland habitats - further increasing the effectiveness of these semi-natural habitats as an important land-use mitigation strategy.

7.3 Research gaps for afforestation:

- Innovative ways to use timber in long-term structures for carbon sequestration
- Best species mixtures for afforestation in Ireland
- Robust carbon sequestration rates of hedgerows and woody habitats on agricultural land
- Genotypes and/or species that are resistant to future threats

8. Impacts of other land-use changes on water quality and biodiversity

In addition to afforestation, we have identified several other areas of potential land-use change that could have positive and negative impacts on biodiversity (summarized in Table 3).

Table 3. Summary of recommendations on how to avoid, minimise, and mitigate potential negative consequences of afforestation and additional identified land-use changes on water quality and biodiversity.

Land-Use Change	**Afforestation**	**Peatland restoration and rehabilitation**	**Livestock farming**	**Drainage of heavy soils**
Recommendations	1. Avoid afforestation of naturally open habitats and deep peat soils 2. Restoration of degraded natural and semi-natural woodlands to improve carbon and biodiversity states 3. Set targets for native mixtures in plantation forests 4. Avoid using planted trees as bioenergy crops 5. Avoid displacing land-use (e.g., intensifying land-use on natural and semi-natural habitats) 6. Disincentivise the use of fire to clear land 7. Promote agroforestry initiatives 8. Rehabilitate peatlands on failed plantation sites 9. Prioritise and extend LiDAR surveys of Teagasc Signpost farms to estimate carbon sequestration of hedgerows and woody habitats on farmland	1. Promote and fund the rehabilitation of decommissioned industrial peatlands 2. Further regulate all peat extraction, including turf and horticultural peat production 3. Consider how turbary rights can be altered (to carbon & biodiversity sequestration rights) or purchased to reduce small scale peat extraction. 4. Identify and map peatland areas related to turf and horticultural peat extraction (non BNM areas)	1. Prevent dairy expansion 2. Use new CAP to incentivise extensification of livestock farming and provision of alternative ecosystem services 3. Reduce the amount of N applied to pastures 4. Use clover and multi-species swards to reduce need for nitrogen application	1. Multi-species swards should not be considered as a replacement for high nature value/semi natural grasslands but can be effective in reducing fertiliser needs. 2. Assess whole of life-cycle impact on GHG due to drainage of heavy soils and subsequent intensification for livestock farming.

8.1 Peatland restoration and rehabilitation

Peatlands are biodiversity hotspots that provide habitat for thousands of unique plant and animal species. Ireland is a global hotspot for peatlands, and peatlands and peat soils extend to over 20% of our land area. In addition to their importance in supporting biodiversity, peatlands are complex systems that have aided in climate regulation for millennia by acting as large carbon sinks. However, their significance for biodiversity conservation and climate mitigation has not always been realized, and long-standing efforts to drain and use them for agriculture and forestry has resulted in large scale degradation of peat habitats throughout Ireland. This results in the loss of unique species, and ultimately decreases their potential to contribute to climate mitigation through loss of soil carbon due to drainage and planting (Jovani-Sancho *et al.*, 2021).

The restoration of peatlands is also important for promoting biodiversity and mitigating greenhouse gas emissions from land use[2]. Bord na Móna has committed to the rehabilitation of over 79,300 hectares of bog, with 19,700 hectares already rehabilitated. These efforts should continue to be supported as they are "win-win" for both climate and biodiversity. Note that the BNM lands equate to ca 5% of the national peatland resource so a full inventory of peatlands should be considered in terms of potential wins for rewetting.

In addition to the peatland areas that were drained for agriculture and forestry, about 5-6% of peatlands have been drained for industrial peat extraction. Negative impacts of peat extraction for climate and biodiversity have long been recognised and peat extraction for fuel on state managed lands has recently ceased. Many of these bogs will be decommissioned and rehabilitated so that they can be returned to semi-natural states to reduce GHG emissions and regeneration of biodiversity habitats.

However, there is still a demand for, and extraction of, horticultural peat at a commercial scale. Smaller scale regional and domestic turf extraction is also ongoing for use in home heating. There are concerns that the cessation of briquette production from Bord na Móna peatland could displace peat extraction to other bogs that lack IPC licensing and regulations. This continued peat extraction will have negative impacts for biodiversity and climate mitigation. Regulation of peat extraction (including turf) would help prevent the expansion of extraction, and resulting consequences for climate, water and biodiversity. Furthermore, the rehabilitation (rewetting and potential restoration to be considered priority where feasible according to SER Standards) of decommissioned bogs should be a top priority for climate mitigation and biodiversity conservation in Ireland as this is a Nature Based Solution that would have strong and immediate positive impacts on our environment.

8.2 Research gaps for peatland restoration and rehabilitation

- Hydrology & GHG impacts of rehabilitating wetlands (blocking drains, etc.)
- Alternative ecological stable states for rehabilitated wetlands and their ecosystem service delivery
- Optimal restoration methods for maximising biodiversity and carbon storage and capture

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[2] We note that as well as benefits for climate and biodiversity, peatland restoration and rehabilitation results in multiple co-benefits for water (regulatory and provisioning services) as well as cultural services. https://thewaterforum.ie/app/uploads/2021/04/Peatlands_Synthesis-Report_Final_April2021.pdf

8.3 Livestock farming

Through the heavy soils programme, Teagasc envision additional grassland in Ireland will come under intensive pasture management allowing a concomitant increase in the national cattle herd (Teagasc, 2021). Drainage of heavy soils will likely negatively impact high nature value farmland – see **Drainage of heavy soils** – thus negatively impacting biodiversity. An effective mitigation strategy that would simultaneously benefit biodiversity is stopping the national dairy herd expansion to prevent more land coming under intensive pasture management. An assured strategy to reduce emissions from agriculture and benefit biodiversity through avoidance of intensification of land use is to reduce the national dairy herd.

The intensive pasture management typical of Irish dairy systems requires high nitrogen fertilizer inputs, the main contributor to nitrous oxide emissions. The intensification of dairying has seen the creation of improved agricultural grassland, a grassland dominated by perennial rye grass which grows well under very high nitrogen inputs. The high nitrogen inputs, in the form of synthetic fertilisers and organic nitrogen (manure) directly contribute to N_2O emissions, a potent greenhouse gas, which also negatively effects grassland and soil biodiversity. Additionally, the high nitrogen inputs are washed into water systems and cause eutrophication issues in estuaries.

Reducing the amount of nitrogen applied to paddocks will reduce N_2O emissions while concomitantly reducing pollution of the waterways. The use of clover and multi-species swards, protected urea, low emissions slurry spreading, and manure additives will aid in reducing the need for high nitrogen application.

8.4 Research gaps for livestock farming

- Creation of habitat for biodiversity and carbon storage and capture on intensive livestock farms
- Methods for ecological intensification of livestock farming for provision of additional ecosystem services

8.5 Drainage of heavy soils

A large proportion of farms in Ireland are located on land that is poorly drained due to natural factors such as soil type, topography, and climate. Teagasc estimates that 30% (0.96 million hectares) of the 3.18 million hectares of nationally managed grassland is imperfectly or poorly drained (Teagasc, 2021). Such poorly drained soils are suboptimal for farming as they remain wet for prolonged periods, resulting in shorter grazing seasons, and lower productivity and profitability. As a potential solution, Teagasc have implemented a 'Heavy Soils Programme' that aims to drain 10% of Ireland's total grassland by 2030 to increase the quality of agricultural land. It has also been suggested that this programme will be beneficial for climate mitigation as the drainage of mineral soils can result in a direct reduction of N_2O emission. However, the benefits for climate mitigation are limited, as draining organic and/or peat dominated soils results in significant emissions of the CO_2 that is naturally sequestered in such soils. The drainage of mineral soils could also lead to an increase in N leaching (Teagasc Greenhouse Gas Working Group, 2019). There are also substantial potentially negative impacts that could result from this scale of soil drainage. For instance, there is likely to be significant overlap between heavy soils and High Nature value farmland ('HNV Distribution', 2015). This indicates that the draining of heavy soils and subsequent intensification of livestock farming will likely reduce the distribution and coverage of high nature value farmland, and therefore negatively impact biodiversity.

Current considerations for biodiversity include planting multi-species swards (i.e., or mixtures of three or more species) as forage. This practice does have environmental benefits, as it can produce similar yields to grass monocultures but with a steep reduction or elimination of fertilizer input. This means that less nitrogen will be applied to the forage crops. It has also been suggested that planting multi-species swards increases biodiversity, however it is important to recognize that multi-species swards are not equivalent to natural biodiversity. Natural grasslands and semi-natural grasslands are rich in biodiversity and support a diversity of native plant and animal species. There are large areas of semi-natural grassland in Ireland, including six types that are protected by the EU Habitats Directive. The natural biodiversity supported by these habitats cannot be replicated by planting multi-species swards of agricultural species. Ultimately, draining high nature value areas and replacing them with multi-species swards represents a net loss in biodiversity.

Teagasc have included rewetting 40,000 hectares of organic grassland soils (out of a total 370,000 hectares of drained organic soils) as a possible climate mitigation method in the second iteration of the Greenhouse Gas Marginal Abatement Cost (Teagasc Greenhouse Gas Working Group, 2019). This action would likely have positive effects on biodiversity and climate. For example, Teagasc has estimated that stopping drainage and restoring natural water tables for 40,000 hectares of grassland would result in 0.44 Mt CO_2-e yr^{-1} of emissions savings (Teagasc Greenhouse Gas Working Group, 2019). As a significant number of emissions (1.4 Mt CO2-e) are generated from drained sites within protected areas, it would be especially beneficial for both climate and biodiversity to rewet protected sites. As an alternative to stopping drainage and completely rewetting 40,000 hectares of grassland, Teagasc proposes that converting 65,000 hectares of nutrient rich, managed grasslands from deep drained to a shallow drained state could result in a similar amount carbon savings. If ambitions were increased and both of these measures would be taken, there would be substantial benefits to both climate and biodiversity. The rewetting of peaty agricultural soils could be a large land use abatement measure and would also provide habitat for many native plant and animal species.

It is also possible that some of these previously drained grasslands have naturally rewetted as drains have fallen into disrepair. However, these grasslands need to be mapped and surveyed to determine whether they have rewetted and to what extent.

8.6 Research gaps for drainage of heavy soils

- Natural capital approach to whole of life-cycle modelling of GHG emissions and biodiversity fluxes from current vs. future land use under drainage and no-drainage scenarios for different soil types.

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Appendix 1. Table summarizing the research needed to accurately assess biodiversity impacts of climate mitigation strategies and/or effective mitigation strategies.

Climate Mitigation Method	Research Gaps
General	• Impacts on biodiversity worldwide of supply chain provision or disruptions due to expansion of renewable energy or changes in land-use in Ireland. For example: sourcing of raw materials for wind turbines or solar panels, changes in imports of fertilisers or livestock feed.
Offshore Wind	• Negative impacts on seabird foraging (especially long-term impacts for key species) • Biodiversity impacts of decommissioning • Optimal artificial reef construction • Impacts on migration pathways for birds and Cetaceans and assessment of alternative migration pathways
Onshore Wind	• Mortality of Irish bat species in relation to wind farms; particularly with respect to population dynamic sensitivities and thresholds • New sensors and monitoring methods (including acoustic, radar and video monitoring) for impacts and testing effects of mitigation measures • Testing curtailment of wind farm operation during weather associated with high mortality and/or during times of high bird and bat activity • Understanding the ecological potential for natural sites to be rehabilitated • How to promote equity and just transition for community buy in to climate mitigation and biodiversity conservation • Cumulative damage estimates at all levels to enable population-wide impacts to be assessed (i.e., turbine, wind farm, and industry levels)
Solar	• Impacts of PV systems on native bird populations • Determine what kinds of functional ecosystems can be established in and persist in Ireland under solar panels with minimal chemical use
Bioenergy	• Predictions/modelling for the potential scale of bioenergy in Ireland without damaging biodiversity • Irish specific taxa and their responses to bioenergy cultivation • Land use planning is needed to prevent displacement of agriculture to natural or semi-natural areas • The quality of the grass product (single species or multi-species swards) in relation to suitability for biomethane and intensive management potentially needed (i.e., avoidance of fertilisers and pesticides)
Afforestation	• Innovative ways to use timber in long-term structures for carbon sequestration • Best species mixtures for afforestation in Ireland • Robust carbon sequestration rates of hedgerows and woody habitats on agricultural land • Genotypes and/or species that are resistant to future threats
Peatland restoration and rehabilitation	• Hydrology & GHG impacts of rehabilitating wetlands (blocking drains, etc.) • Alternative ecological stable states for rehabilitated wetlands and their ecosystem service delivery • Optimal restoration methods for maximising biodiversity and carbon storage and capture
Livestock Farming	• Creation of habitat for biodiversity and carbon storage and capture on intensive livestock farms • Ecological intensification of livestock farming for provision of additional ecosystem services
Drainage of Heavy Soils	• Whole of life-cycle modelling of GHG emissions from current vs. future land use under drainage and no-drainage scenarios for different soil types.

Appendix 2. Project Brief: Review of impacts of climate mitigation measures on biodiversity. 2 months.

The aim of this small-scale study is to develop an understanding of the impacts of Greenhouse Gas emissions reduction measures in key economic sectors on biodiversity in Ireland. The EU Biodiversity Strategy and legal obligations under to the Birds and Habitats Directives, the Water Framework Directive (WFD) and the Marine Strategy Framework Directive (MSFD) provide an important context to this study.

Global Actions consistent with the Paris Agreement will likely reduce the risk of major disruption to biodiversity in Ireland from climate change. Some mitigation measures can impact negatively on the terrestrial, freshwater and marine environments. Of particular concern in this regard are the potential measures undertaken in the energy and Agriculture and Land Use (AFLOU) sectors.

Energy: The Climate Action Plan 2019, and the Programme for Government 2020 envisage significant expansion of renewable energy generation in Ireland, including onshore and offshore wind and solar. This will lead to large scale deployment of new infrastructure in Ireland, which will have a potential impact on terrestrial and marine biodiversity and ecosystems. The scope of existing regulation under the Habitats Directive; the WFD, and the MSFD to prevent adverse impacts on biodiversity and environmental degradation needs to be considered.

Land use: The Climate Action Plan 2019, and the Programme for Government 2020 envisage significant initiatives in changing land use and land use management to prevent carbon losses, enhance removals and also provide resources for bioenergy and the wider bioeconomy. However, management practices within forestry have known impacts on biodiversity. With the expected additional requirements for changes in land use and agricultural practices/carbon farming, etc., the impact of these mitigation measures on biodiversity and the water environment needs to be better understood, including the influence of location and scale of the development and management measures.

The objectives of this desk review are to

- Outline the key potential impacts of climate mitigation measures in the energy and land use sectors including:
    - The impacts of offshore renewables on marine ecosystems in the context of existing relevant regulations (e.g. WFD, MSFD), the impact of on-shore renewable energy, wind solar on the meeting of N2000 and WFD targets and consistency with the EU Biodiversity Strategy
    - Impacts of cultivation of energy crops on biodiversity including the meeting of N2000 and WFD obligations
    - Impacts of afforestation and other potential land-use changes on water quality and biodiversity including the meeting of N2000 and WFD obligations and consistency with the EU Biodiversity Strategy
- Identify the factors that influence these impacts (scale, location etc.) with reference to current targets and plans for Ireland (e.g. scale and planned location of off-shore renewables and afforestation)

The outputs should be

- A brief literature review which addresses the stated objectives of this study, to include:
    - Set of recommendations to inform and frame the setting of carbon budgets that are in line with biodiversity and water quality obligations, including Birds and Habitats Directives, the WFD, the MSFD and the EU Biodiversity Strategy,

- Identify potential knowledge gaps for future work in this area