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Biodiversity, climate change and energy

A knowledge synthesis and analysis of the links between biodiversity, climate change and energy, and the relevant EU policies, projects and initiatives

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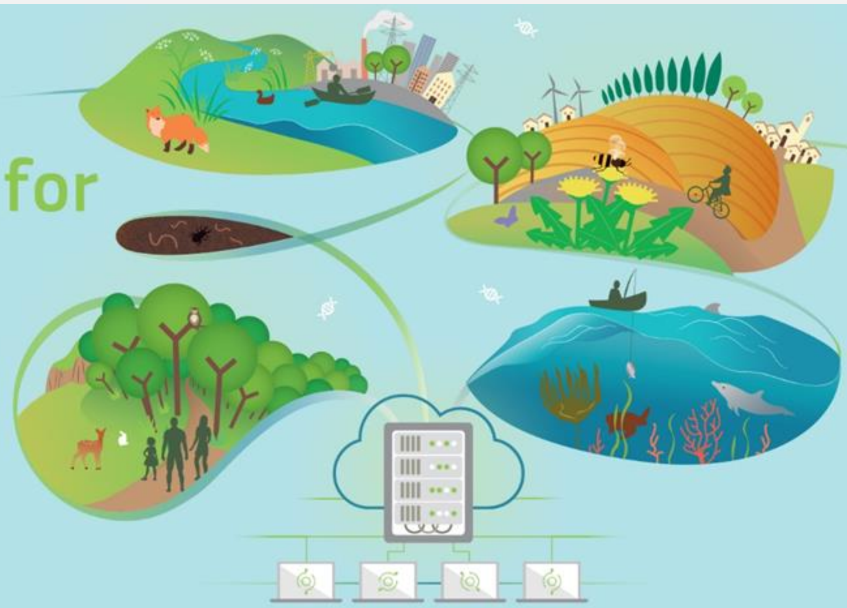

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Abstract

We are facing a planetary emergency caused by interdependent biodiversity loss and climate change. Whilst climate change is itself a major driver of biodiversity loss, climate change and biodiversity loss also share many anthropogenic drivers and reinforce each other's impacts. It is thus crucial for actions directed at climate change mitigation and adaptation to be synergistic with those addressing biodiversity loss. Actions addressing the two crises of climate and biodiversity separately, while overlooking their intertwined and mutually reinforcing nature, are likely to fail. The energy sector is a key element of climate change mitigation strategy, which, if poorly planned, could adversely affect biodiversity. In this study we describe the synergies and potential trade-offs in combating climate change and biodiversity loss, as well as the relevant EU policies and projects.

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1 Introduction

This study is part of a series initiated by the Knowledge Centre for Biodiversity (KCBD) to raise awareness on the importance of embedding biodiversity concerns in all relevant policy domains. The series describes the efforts of the European Union in this direction, key to effecting transformative change and a green transition. The content targets a wide audience, prioritising accessibility for the layperson as well as interest for specialists, policymakers and researchers. All the reports in the series follow a common structure, which was originally designed for the thematic pages for the website of the KCBD ([1]) and determined collectively with other knowledge centres as part of the Knowledge for Policy (K4P) initiative of the European Commission. This report focuses on the importance of integrating biodiversity-related concerns in the policy domains of climate change and energy, and describes the relevant EU policies, projects and initiatives.

1.1 Global state of play on biodiversity, climate change and energy

We are facing a planetary emergency caused by interdependent biodiversity loss and climate change. Whilst climate change is the third-most important driver [1] of biodiversity loss, it also interacts with and exacerbates other drivers. At the same time, climate change and biodiversity loss share many common anthropogenic drivers [2], including the overexploitation of natural resources, unprecedented energy consumption and transformation of land-, freshwater- and sea-scapes. They also reinforce each other: increased atmospheric greenhouse gas (GHG) concentrations lead to global warming, altered precipitation regimes, frequent extreme weather events, and oxygen depletion and acidification of aquatic environments, which adversely affect biodiversity. Reciprocally, changes in biodiversity affect the climate system, especially by affecting the nitrogen, carbon and water cycles. Phytoplankton in particular play a crucial role in climate regulation, and their reduced growth due to ocean acidification could trigger catastrophic climate change. Finally, biodiversity loss weakens the climate adaptation capacity of ecosystems and human societies. These interactions generate complex feedback cycles with increasingly pronounced, less predictable and potentially irreversible outcomes. Under current trends we risk crossing cascading tipping points in the earth system.

The goals of climate change mitigation and adaptation and reversing biodiversity loss are strongly synergistic: nature is a vital ally against climate change [1]. Actions to attain these goals separately, while overlooking their intertwined and mutually reinforcing nature, are likely to fail. In the worst case, actions directed at tackling one can hinder the solution of the other. The energy sector is key here: intensified renewable energy provision is a crucial element of climate change mitigation strategy, which, if poorly planned, could adversely affect nature and biodiversity [3]. Whilst most scientists and policymakers now recognise the need for an integrated approach, research communities as well as governance bodies - United Nations Framework Convention on Climate Change (UNFCCC)/Intergovernmental Panel on Climate Change (IPCC) vs. Convention on Biological Diversity (CBD)/Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) - dealing with climate change and biodiversity remain somewhat distinct. The recent joint IPCC-IPBES report [2] emphasised that this functional separation can entrain incomplete understanding of the interconnectedness of the two crises, thus missing opportunities to exploit the synergies and minimise the trade-offs in tackling them.

Among the important synergistic actions are nature-based solutions (NBS) [Section 2.1.2]: actions to protect and restore nature that also tackle climate change mitigation and adaptation. Halting and reversing the loss and degradation of natural ecosystems will be crucial for biodiversity protection as well as climate change mitigation, with large adaptation co-benefits. Sustainable agriculture and forestry can improve adaptive capacity, enhance biodiversity, increase carbon storage in farmland and forests, and reduce greenhouse gas emissions. But these measures can only succeed in tandem with ambitious reductions in GHG emissions; they rely on longevity, and a narrow focus on rapid carbon sequestration is likely to backfire.

There are also potential trade-offs. Measures narrowly focused on climate change mitigation and adaptation can have direct and indirect negative impacts on nature and nature's contributions to people. To limit global warming to 1.5°C and avoid disruptive climate change, anthropogenic GHG emissions must reach net zero by 2050. This clearly requires a major transition from fossil-fuel dependence to large-scale renewable energy deployment, as well as reduced and more efficient energy use. However, renewable energy expansion requires

[1] https://knowledge4policy.ec.europa.eu/biodiversity_en

significant land assets and mineral extraction, and could, if poorly managed, come at high cost to valuable ecosystems.

Planting bioenergy crops in monocultures over large tracts of land is detrimental to ecosystems. Studies indicate [4,5,6] that the biodiversity footprint of bioenergy is the highest of all renewable energy options, and that its benefits for power consumption can be overturned by its environmental costs [5]. Biofuel feedstock cultivation affects biodiversity primarily through land-use change, and also through overexploitation, pollution, invasive species, climate change and other factors. Increased demand for forest biomass is harming biodiversity via more intensive forestry. Forestry measures such as afforestation in ecosystems that have not historically been forests, and reforestation with monocultures, can contribute to climate mitigation but are often detrimental to biodiversity.

The production of wind energy, hydropower, solar photovoltaics (PV), and electric vehicles also involves potential trade-offs for biodiversity, which should be taken into account from the outset. Solar plants can have high land requirements, modify local ecosystems, and lead to the conversion of natural habitat or increased pressure for agricultural intensification. Frequent collision with wind turbines and transmission lines could put vulnerable migratory species of birds and bats at risk. Dams impact freshwater ecosystems, leading to abrupt disconnection of water, sediment and life. Mining for minerals used in wind turbines, PV systems and electric car motors and batteries can adversely affect natural ecosystems, as can the disposal of decommissioned solar panels, motors and batteries.

Yet renewable energy, along with reduced and more efficient energy use, remains a priority for mitigating climate change in ways that benefit biodiversity. Insufficient progress on cutting GHG emissions through these means is prolonging fossil fuel use and increasing reliance on geoengineering options such as negative emission technologies (NETs) to compensate for the ensuing emissions. The role of NETs in mitigation pathways to net zero by 2050 has been enhanced in recent IPCC reports [7,8], risking potentially greater impacts on nature while also jeopardising decarbonisation of the economy. Another risk is the later inclusion of more intrusive geoengineering options such as Solar Radiation Management (SRM) with possibly irreversible impacts on nature.

Section 2 of this report is devoted to EU action to tackle these challenges. In Section 2.1 we discuss the specific context of each of the issues mentioned above, as well as the EU policies addressing them. Section 2.2 is devoted to the relevant EU projects and initiatives.

Figure 1. Biodiversity, energy and climate infographic as displayed by the EC Knowledge Centre for Biodiversity

Source: Paivi Sund

2 EU action on biodiversity, climate change and energy

In this section we discuss the main EU policies [Section 2.1] as well as projects and initiatives [Section 2.2] relevant to the biodiversity, climate change and energy nexus, with a view to mapping EU actions that address the interlinked planetary crises of climate and biodiversity.

2.1 EU policies on biodiversity, climate change and energy

This section mainly covers the EU's domestic policies in areas relating to the biodiversity, climate change and energy nexus. The EU's international engagement and policies relating to biodiversity and climate are covered under the topic “biodiversity and its global governance” [9].

Biodiversity, climate and energy are among the main areas of action of the European Green Deal (EGD) [10]. Action on biodiversity is covered under the domain "Environment and oceans," and enshrined in the EU Biodiversity Strategy for 2030 [11]. Priority actions on climate change [12] consist of the Climate Law [13], the Climate Pact [14], and the Adaptation Strategy [15] – as well as international action, whose biodiversity relevance is covered elsewhere [9]. In the energy domain [16], the policy focus is mainly on security and affordability, energy system integration, energy efficiency and renewable energy. Agriculture is a separate domain under the EGD but here we only focus on aspects of agriculture that relate to the biodiversity, climate and energy nexus, such as biofuel feedstock cultivation and agro-forestry. Other aspects will be covered under the forthcoming topic "biodiversity and agriculture."

The EU's 8th EAP (April 2022) or General Union Environment Action Programme to 2030 [17], while strongly supporting EGD objectives, goes beyond the EGD. Its priority objectives set out a direction for Union policymaking, building on, but not limited to, the commitments of the strategies and initiatives of the EGD. It stipulates that the green transition should enable systemic change, recognising that our wellbeing and prosperity depend on a healthy environment in which biodiversity is conserved, ecosystems thrive, and nature is protected and restored, leading to increased resilience to climate change, weather- and climate-related disasters and other environmental risks. Ensuring effective climate and biodiversity mainstreaming and proofing of the Union budget, as well as consistency between climate and biodiversity funding, are identified as key enabling conditions for attaining the EGD's priority objectives.

2.1.1 Linkages between EU policies on biodiversity, climate change and energy

In this section we describe how, and to what extent, the main EU policies on biodiversity, climate change and energy reflect the strongly interlinked nature of these three policy domains. The subsequent sections 2.1.2, 2.1.3 and 2.1.4 consider some of these issues in more detail, along with the EU policies addressing specific aspects.

2.1.1.1 Climate and energy in EU biodiversity policy

The EU Biodiversity Strategy for 2030 (EU-BDS 2030) [11] underscores that the causes of, as well as solutions to, the biodiversity and climate crises are intrinsically linked. It emphasises the need for NBS [Section 2.2], which are essential for emission reduction and adaptation to climate change. In this spirit, the EU-BDS 2030 calls for the protection of at least 30% of EU land and sea areas, of which at least a third should be strictly protected in order to allow special care for high biodiversity carbon-rich areas that are most vulnerable to climate change. Currently, the EU strictly protects only 3% of its land and less than 1% of its marine areas.

To ensure effective nature restoration that increases the EU’s resilience and contributes to climate change mitigation and adaptation, the EU-BDS 2030 proposed legally binding EU targets to restore degraded ecosystems, in particular those with the most potential to capture and store carbon, and to prevent and reduce the impact of natural disasters. Such targets were enshrined in the EU's landmark Nature Restoration Law [18] proposed by the Commission in June 2022. They include restoring, by 2030, significant areas of degraded terrestrial and marine ecosystems, where biodiversity loss due to global warming has been especially acute, with special emphasis on carbon-rich ecosystems. In November 2023 a provisional political agreement was reached between the Council and the European Parliament on an amended proposal, which was adopted by the Parliament on 27 February 2024; the new regulation still has to be formally adopted by the Council before entering into force.

Intensive agriculture is a major driver of climate change as well as biodiversity loss: synthetic fertiliser use and land conversion are the biggest contributors. Agricultural measures addressing biodiversity and climate change simultaneously are a crucial component of the EU-BDS 2030. These include a 50% reduction in nutrient loss from fertilisers, expected to lead to a 20% reduction in fertiliser use, bringing back at least 10% of agricultural land under high-diversity landscape features that enhance carbon sequestration and support climate adaptation, bringing 25% agricultural land under organic farming and increased uptake of agro-ecological practices, and a 50% reduction of chemical and more hazardous pesticides, which will in turn be facilitated by a transition to natural farming methods. The EU-BDS 2030 supports increased agro-forestry under rural development for its multiple benefits to both biodiversity and climate. It also includes the planting of 3 billion new trees, and an ambitious Urban Greening Plan for cities. Installing green infrastructure and trees will help cool urban areas and mitigate the impact of natural disasters.

Forests are crucial for biodiversity, climate regulation and carbon sequestration, apart from their multiple other benefits. In addition to strictly protecting all remaining EU primary and old-growth forests, the EU-BDS 2030 calls for a higher quantity, quality and resilience of its forests, notably against mounting climate-related disasters like fires, droughts and pest-and-disease outbreaks. Forests are also threatened by increasing energy demand: wood-based bioenergy already supplies 60% of the EU's renewable energy. The new EU Forest Strategy for 2030 [19] is dedicated to these issues. The biodiversity relevance of climate change and energy strategies is discussed in later sections. The EU-BDS 2030 prioritises "win-win solutions" for energy generation such as ocean energy, offshore wind, which also allows for fish stock regeneration, solar-panel farms that provide biodiversity-friendly soil cover, and sustainable bioenergy.

2.1.1.2 Biodiversity in EU climate policy

Under the climate rubric of the EGD, the European Climate Law [13] commits the EU to climate neutrality by 2050 and sets an immediate target of at least 55% net reduction in GHG emissions by 2030 compared to 1990 levels. It aims to achieve this mainly by cutting emissions, investing in green technologies and protecting the natural environment. It acknowledges the IPBES warning [1] on the worldwide erosion of biodiversity, with climate change as its third-most important driver, and reiterates the need to protect ecosystem integrity and biodiversity against climate change [13] in the context of the UN 2030 agenda for sustainable development [20] and the objectives of the Paris Agreement, and to maximise prosperity within planetary boundaries, increase resilience and reduce vulnerability of society to climate change. Actions should follow the precautionary and 'polluter pays' principles established in the Treaty on the Functioning of the European Union, as well as the 'energy efficiency first' principle of the Energy Union and the 'do no harm' principle of the European Green Deal. While stressing the essential role of carbon sinks in achieving climate neutrality, the climate law calls for ecosystem restoration to assist in maintaining and enhancing natural sinks, enhancing adaptation capacities and resilience and minimising climate impacts, while bringing considerable co-benefits for biodiversity. The increasing frequency and impact of heat waves, floods, droughts, forest fires and other extreme events, as well as sea-level rise and melting glaciers, have already substantially impacted ecosystems, carbon sequestration and storage capacities of forest and agricultural land. Preparing early for such impacts is cost-effective, and the climate law emphasises NBS [Section 2.1.2] for collectively addressing climate change mitigation, adaptation and biodiversity protection. Maintaining, managing and enhancing natural sinks in the long term, while protecting and restoring biodiversity, is among the intermediate Union climate targets.

The European Climate Pact [14] invites people, communities and organisations across the EU to participate in climate action and build a greener Europe. Developing green areas is among its current priority actions to build resilience in the face of climate and health threats. In cities green urban areas both absorb emissions and reduce excessive temperatures, while in rural areas they provide multiple benefits for biodiversity, agriculture and ecotourism. Addressing the EU-BDS 2030 target of three billion new trees by 2030, the Climate Pact supports local communities, organisations and individuals committed to tree-planting and caring initiatives while linking up with the new European Urban Greening Platform [21]. To ensure that enough land area is returned to vegetation, the Climate Pact will provide [14] information to local and regional authorities, solutions to restore, protect and enlarge green urban areas, and a forum for dialogue and cooperation between communities, landowners and local governments. Solutions will build on existing policies and initiatives, and draw on findings from research projects, such as NBS [Section 2.1.2].

The new EU Strategy on Adaptation to Climate Change [15] adopted in 2021 underscores the need for systemic action, including NBS. Whilst recognising the urgency to address increasingly frequent and severe extreme events such as heatwaves, forest fires, droughts, hurricanes and pest outbreaks, it stresses that slow onset events including biodiversity loss and land and ecosystem degradation are equally destructive over the long term. Given the systemic nature of adaptation policy, it seeks to take action in an integrated manner with other EGD initiatives such as the EU-BDS 2030, the new Forest Strategy to 2030 [19], the Soil Strategy [22], and the Circular Economy [23] and Zero Pollution [24] Action Plans. It cites major shifts expected over this century in the EU's terrestrial ecosystems and vegetation types, including protected areas (PAs). Water cycle and temperature changes, as well as sea-level rise, will additionally impact ecosystems. The ocean is expected to reach unprecedented conditions with increased temperatures, further acidification, and oxygen decline. In this context, the strategy prioritises better understanding of the interdependencies between climate change, ecosystems, and the services they deliver. The impact assessment accompanying the Adaptation Strategy [25] identifies insufficient knowledge to support decision-making as a key problem, pointing in particular to the complete absence of losses such as ecosystem degradation and biodiversity loss, from existing datasets. Among the key drivers, it identifies insufficient public and private sector adaptation investment, partly due to the public good problem: the wider benefits of adaptation for society are not necessarily captured by private financial return on investments. In light of all this, the Adaptation Strategy calls for science-based, robust ecosystem restoration and management to minimise risks, improve resilience, and ensure the continued delivery of vital ecosystem services: food provision, air and water purification, flood protection, biodiversity, and climate change mitigation. It advocates more long-term investment in NBS for climate resilience, given their numerous environmental, social and economic co-benefits for adaptation, mitigation, disaster risk reduction, biodiversity, and health.

2.1.1.3 Biodiversity in EU energy policy

The production and use of energy accounts for more than 75% of the EU’s GHG emissions [16]. Decarbonising the EU’s energy system is therefore critical for attaining the climate target of 55% reduction in GHG emissions by 2030 and the long-term commitment of carbon neutrality by 2050. The EGD focuses on three key principles for reducing GHG emissions from energy consumption: ensuring a secure and affordable energy supply, developing a fully integrated, interconnected and digitalised energy market, and cleaning the energy system [26] via improved energy efficiency and increased renewable energy deployment. Renewable energy (RE) is fast gaining a strong foothold in the EU. The share of renewable sources in the EU's gross final energy consumption more than doubled from 9.6% in 2004 to 22.1% in 2020 [27]. Currently, wood-based biomass provides 60% of EU renewable energy. Renewable electricity generation is dominated by wind (36%), hydropower (33%) and solar energy (14%). However, substantial further RE expansion will be required for attaining the climate targets. The EU has thus proposed to raise its binding target for renewable sources in the energy mix from the 32% stipulated in the 2018 recast Renewable Energy Directive (REDII) [28] to 40% (and possibly 45% under the 2022 REPowerEU plan) [29], and to achieve an overall reduction of 36-39% [26] in final and primary energy consumption by 2030. The revised Renewable Energy Directive (REDIII) [30], which was adopted in October 2023, raises the EU's binding renewable target for 2030 to a minimum of 42.5%, with the aspiration to reach 45%.

This increased ambition on renewable energy is a welcome revision due to the urgency of climate change mitigation – including for biodiversity conservation. However, biomass consumption and the expansion of wind, solar photovoltaic, hydropower and other RE installations do also pose significant challenges and issues for nature conservation and biodiversity. Many of these are already being addressed in policies or are currently under investigation, while others are yet to be investigated. Moreover, this is an emergent area with new challenges appearing regularly, as well as new research and innovation on renewable energy. These call for further attention and regular monitoring of impacts of RE expansion on ecosystems and biodiversity. The section on biodiversity and climate change mitigation: renewable energy [Section 2.1.3] is dedicated to discussing these challenges and issues in more detail, along with the relevant EU policies.

2.1.1.4 Potential challenges for biodiversity

The expansion of renewable energy (bioenergy, hydropower, solar, wind, etc.) presents potential trade-offs for ecosystems and biodiversity if nature conservation concerns are not incorporated from the outset in RE policies. To this end, the recast Renewable Energy Directive [28], further revised in 2023, extended sustainability criteria to cover a larger range of biomass, and added new criteria for some categories. These issues, as well as the incorporation of nature-conservation concerns in policies relating to other specific RE sources, are discussed in detail in Section 2.1.3 covering renewable energy.

It should also be noted that the EU's net emission reduction targets include carbon removal mechanisms to compensate for what are deemed unavoidable emissions in other sectors. This includes the proposal for raising the natural carbon removal target [26] from 225 Mt to 310 Mt by 2030 by restoring Europe’s forests, soils, wetlands and peatlands. A quick and cheap solution with co-benefits for biodiversity if implemented correctly, it could backfire if prioritising rapid carbon sequestration leads to plantations of monocultures or fast-growing species that interfere with local ecosystems. Net emissions reduction also includes the deployment of negative emission technologies (NETs) involving carbon capture and storage [31]. Here too, prioritising rapid carbon sequestration could occur at the expense of nature and biodiversity, as discussed in Section 2.1.4.

It is thus of paramount importance for successfully delivering the EGD that an integrated approach to biodiversity conservation and climate change be deployed from the outset. Sections 2.1.2, 2.1.3 and 2.1.4 are dedicated to analysing these issues, along with the relevant EU policies and strategies. Section 2.1.2 describes how NBS can optimise the strong synergies between addressing climate change and biodiversity loss, whilst Sections 2.1.3 and 2.1.4 on biodiversity and climate change mitigation are devoted to potential trade-offs as well as synergies between biodiversity conservation and climate change mitigation measures such as renewable energy expansion [Section 2.1.3] on the one hand, and geo-engineering or NETs [Section 2.1.4] on the other.

2.1.2 Nature-based solutions for biodiversity and climate

NBS have been referred to in other sections on biodiversity and climate change policies in connection with the EU-BDS 2030, the EU Climate Law and the Adaptation Strategy among others. This section highlights their role as key to exploiting synergies between addressing climate change and biodiversity loss, identifies the main challenges in deploying them, and describes the relevant EU policies.

2.1.2.1 The context

NBS are being widely hailed [32] as a win-win for tackling biodiversity loss and climate change, whilst also supporting sustainable development. The NBS concept is grounded in the knowledge that biodiversity loss and climate change have several shared drivers and hence also shared solutions. The United Nations Environment Assembly (UNEA) Resolution on Nature-Based Solutions (March 2022) for supporting sustainable development [33] defines NBS as *actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human wellbeing, ecosystem services and resilience and biodiversity benefits.* The definition does not include 'nature-derived' solutions, such as the use of wind, wave and solar energy, or 'nature-inspired' solutions, such as design of materials modelled on biological processes.

NBS range from [34] minimal or no intervention, such as establishing conservation areas, to the creation of new ecosystems, such as community gardens, urban parks, or mangroves. They represent an evolution of terms used to express similar ideas, such as urban forestry, green and blue infrastructure, or the delivery of ecosystem services. The umbrella concept of NBS [35] also encompasses ecosystem-based adaptation, ecosystem-based disaster risk reduction, low-impact development, water-sensitive urban design, sustainable urban drainage systems, and ecological engineering. These concepts are applicable across strategic, spatial planning, soft engineering, and performance dimensions. The most frequently used of these concepts at EU level have been regrouped in an online glossary on the Resources Hub OPPLA, the EU repository on NBS [36].

The Nature-Based Solutions for Climate Manifesto [37] developed for the 2019 UN Climate Action Summit calls NBS a fundamental part of action for climate and biodiversity. It cites authoritative research [38] indicating that NBS can provide over one-third of the cost-effective climate mitigation needed to achieve 2030 climate goals by unlocking nature's mitigation potential [39]. About 62% of this contribution is estimated to come from [40] NBS in forests, 24% from NBS in grasslands and croplands, 10% from peatlands, and 4% from coastal and marine ecosystems. Many NBS are already being delivered and they can be scaled up exponentially if they are fully valued and receive proper investment. The manifesto points to four areas of urgently needed priority action to ensure this:

1. Increasing and mainstreaming NBS within national governance, climate action and climate policy-related instruments.
2. Enhancing regional and international cooperation.
3. Generating the shifts needed in domestic and international governance and finance.
4. Scaling up NBS for mitigation, resilience and adaptation in key areas.

Seventy governments, private sector, civil society and international organisations signed up to the manifesto [37], and NBS expansion has been identified as an essential step towards achieving the goals of the UN Decade of Ecosystem Restoration. NBS underpin the Sustainable Development Goals by supporting vital ecosystem services, biodiversity, access to fresh water, improved livelihoods, healthy diets and food security from sustainable food systems. Their multiple benefits have been highlighted in the UN-Habitat's new Urban Agenda 2030 [41] and the Convention of Biological Diversity's Global Biodiversity Framework (2022) [42]. They also contribute to the objectives of other international agreements, such as the Sendai Framework for Disaster Risk Reduction. The IUCN Global Standard for NBS and the EC Handbook on evaluating the impact of NBS [34] are expected to greatly contribute to a more consistent understanding, implementation and measurement of the impact of this concept globally.

The IPCC 6th assessment report (2022) [43] cites NBS as exemplary in demonstrating how innovative ideas can expand the climate solution space. While the mitigation role of increasing forest cover has dominated earlier discussions, the role of NBS in promoting adaptation of ecosystems and human societies is being increasingly emphasised. The report points to mounting evidence that diverse, native tree species plantations are more resilient to climate change than fast-growing monocultures, often of exotic species. At the same time, other natural ecosystems such as savannahs, grasslands, peatlands, wetlands and mangroves have considerable value as carbon sinks as well as for providing other ecosystem services such as hydrological regulation, coastal protection, maintaining biodiversity and contributing to human livelihoods. The report cautions against trade-offs between biodiversity, carbon sequestration and water use that can result from aggressive reforestation or afforestation, especially of non-forest land, or for the sole purpose [44] of increasing carbon sinks through bioenergy with carbon capture and storage.

Whereas the potential of NBS to provide multiple benefits in terms of climate change adaptation and mitigation, biodiversity conservation and other goods and services is widely recognised, NBS are themselves vulnerable to climate change impacts, especially at higher warming levels [43, 45]. As increases in the frequency, intensity and persistence of extreme events are reducing the time available for natural systems to recover or adapt, there is an urgent need to build resilience and assist ecosystem recovery following extreme events. Furthermore, to ensure the long-term effectiveness of NBS, their design must take into account how systems will be affected by future climate change. To address the uncertainty inherent in climate change projections, the IPCC 6th assessment report calls for inclusive and adaptive management pathways that keep open many options and include periodic re-evaluation. Further work based on ecological models is also needed to assess the performance of NBS under different climate change scenarios [45].

Demand for NBS is increasing globally [35] due largely to their mainstreaming in international policy, as well as initiatives by citizens and actors who recognise their multiple benefits. Investment, however, remains a challenge. The UNEP State of Finance for Nature report (2021) [46] estimates current global annual investment in NBS at USD 133 billion, mostly from public sources. To meet climate change, biodiversity and land degradation targets, it calls for a tripling of investment in NBS by 2030 and a quadrupling by 2050. The World Economic Forum (2020) has estimated that over half the global GDP, USD 44 trillion, is potentially threatened by nature loss while the transition to a nature-positive economy could create 395 million jobs by 2030. The UNEP report on the State of Finance for Nature in the G20 (2022) [47] builds on this report, revealing that the current G20 investment in NBS of USD 120 billion per year is insufficient, and private-sector investments are particularly inadequate. It calls on G20 countries to scale up annual NBS spending to USD 285 billion by 2050 to tackle the interrelated nature, climate, and land degradation crises, on which much of our economies depend.

2.1.2.2 EU research informing policy on nature-based solutions

A nature-based economic approach is complementary to EU goals such as a Circular Economy and Bioeconomy that propose viable pathways towards sustainable development. However, while the economic relevance of the circular economy and food and bio-based industries has been extensively debated and researched, much less work has gone into examining the potential economic benefits of NBS or the challenges facing nature-based enterprises (NBE) in delivering NBS. The Commission report (2022) highlighting the vital role of NBS in shifting towards a nature-positive economy [35] is a first step in addressing knowledge gaps in this area. Based on extensive consultations, it profiles various activities where NBE are engaged in delivering NBS. It calls for increased corporate investment in NBS, further supporting as well as going beyond current natural capital and circular economy approaches. By raising awareness on crucial issues such as ‘greenwashing’ by the corporate sector, it informs recommendations for realising a robust transition to a nature-positive economy. The report is aimed specifically at economic policymakers but is of high relevance for policymakers across multiple domains, public sector institutions and agencies, researchers, civil society and NGO representatives, investors and financial institutions, industry and NBE.

Robust evaluation of the impacts of NBS is essential for supporting practitioners in improving quality, efficiency and effectiveness at various stages of their implementation. The recent Commission report (2022) on evaluating the impact of nature-based solutions [34] provides a summary of key principles in developing an impact evaluation framework, including a theory of change, and selecting appropriate impact indicators and high-quality data collection methods. The recommended indicators include climate resilience, biodiversity, water management, natural and climate hazards, green space management and air quality. The report presents four European NBS case studies with diverse geographies and challenges, thus illustrating how impact evaluation can be tailored to local contexts.

Building on the G20 report [47], the Commission's Nature-Based Economy working group published the draft White Paper "From Nature-Based Solutions to the Nature-Based Economy" (2021) [48] calling for an increase in private-sector investment in NBS from 14% of total investment in 2021 to 40% by 2030. It proposes policy measures at global, EU, national and local government levels: systemic measures needed for long-term transformative change, as well as immediate short-term actions to boost the market for NBS. The results of the White Paper consultation process [49] will provide input for the forthcoming EC Expert Publication on the Nature-Based Economy. Systemic measures proposed at the EU level include improving policy alignment with NBS in all relevant policies and strategies; investing in research to optimise synergies between the nature-based economy and other Green Deal principles; stimulating NBS market development and accelerating take-up of corporate and SME valuation of nature. Short-term actions proposed include tripling EU NBS investment by 2030 and quadrupling it by 2050 as per the recommendations of the UN report [46]; stimulating knowledge exchange within Europe as well as internationally, in particular for the Global South; stimulating private-sector supply of NBS; developing more comprehensive standards for NBS, and supporting platforms, networks and NBS market events.

2.1.2.3 Nature-based solutions in EU policy

NBS are key to the European Green Deal, in particular the policies relating to biodiversity and climate change. The EU-BDS 2030 [11], the new EU Climate Adaptation Strategy [15] and the European Climate Law [13] prioritise NBS for addressing climate mitigation and adaptation and conserving biodiversity. Key NBS named include protecting and restoring wetlands, peatlands, coastal and marine ecosystems; deploying green infrastructure and planting trees; and promoting and sustainably managing forests, grasslands and farmland. In 2020 the EU-BDS 2030 proposed legally binding targets to restore degraded ecosystems, in particular those with the most potential for carbon sequestration and disaster risk reduction. The Nature Restoration Law, which was adopted by the European Parliament in February 2024 and still has to be adopted by the Council before entering into force, includes restoration targets for degraded terrestrial and marine ecosystems, with special emphasis on carbon-rich ecosystems. To reverse the loss of green urban systems and improve connectivity between green spaces, the Commission has called on cities to develop ambitious urban greening plans including urban forests, parks, farms meadows and hedges, green roofs and walls, and tree-lined streets. To this end, it has set up an EU Urban Greening Platform [21] under a new Green City Accord [50] with cities and mayors, in close coordination with the European Covenant of Mayors.

The new Adaptation Strategy aims at more systemic adaptation centred around larger-scale NBS implementation. Given their multiple benefits and low costs, a bigger role is envisaged for NBS in land-use management and infrastructure planning. Apart from biodiversity protection, carbon sequestration and climate resilience, NBS sustain healthy soils and water quality, and reduce flooding risks. In coastal and marine areas they enhance coastal defence and reduce the risk of algal blooms. The Adaptation Strategy calls for improved quantification and communication of the environmental, social and economic benefits of NBS in order to enhance take-up of these multipurpose "no regrets" solutions. In November 2022 the Commission presented a proposal for an EU-wide voluntary certification framework for carbon removals [51], which would enable robust monitoring and quantification of the climate benefits of many NBS. A provisional agreement with the European Parliament and the Council was reached in February 2024. The Commission will continue to incentivise and assist MS in rolling out NBS through assessments, guidance and funding. Its European Business and Biodiversity initiative [52] will pay special attention to incentivising NBS and eliminating barriers to their take-up, as part of the European Climate Pact [14].

The urgent need for increased finance and long-term investment in NBS has been emphasised in all relevant EU strategies and studies. Investments in NBS must be viable over the long term, because climate change is amplifying pressure on ecosystems. In line with the European Green Deal Investment Plan (2020) [53], targeted support can be unlocked under various EU funding programmes, such as Horizon Europe, the LIFE programme [54], Common Agricultural Policy funds [55] and Cohesion Policy funds. Under InvestEU [56], an ambition to mobilise at least €10 billion over the next 10 years for natural capital and the circular economy was set in the EU-BDS 2030 (see KCBD thematic pages on biodiversity and finance) [57]. The EU Sustainable Finance Taxonomy [58] will help guide investment towards NBS deployment. However, attracting financial investment in nature-based projects, in particular from private sources, raises some challenges and requires a range of financing mechanisms as well as regulatory interventions to provide adequate incentives [59].

2.1.3 Biodiversity and climate change mitigation: renewable energy

This section highlights how renewable energy expansion, essential for climate change mitigation, poses challenges for biodiversity, how trade-offs can be minimised and co-benefits maximised, and provides an overview of the EU policies addressing these issues.

The context

Attaining global climate mitigation goals for 2030 and 2050 clearly entails a systemic transition from fossil fuel dependence to large-scale renewable energy deployment. However, a poorly managed transition could create conflicts between global climate change mitigation and biodiversity conservation, and come at high cost to ecosystems [4]. Whilst the twin goals of climate change mitigation (and adaptation) and reversing biodiversity loss are strongly synergistic, their planning in isolation will reduce [3] the effectiveness and momentum of both efforts.

The largest increase in global renewable energy generation by 2030 is expected from wind and solar [60] sources. Bioenergy is expected to maintain a steady increase [61], mainly to support the heating sector. Hydropower accounted for the largest share of total renewable energy generation in 2020, but its share is expected to decline globally [62]. While different RE technologies have differing impacts on biodiversity and ecosystems, they are not mutually replaceable: each has its limitations and cannot cater to all energy sectors. Bioenergy is mainly used for heating and transport fuel, solar PV and wind for electricity, and hydropower for electricity and energy storage.

Renewables in Europe

Currently, wood-based biomass is the main source of renewable energy [19], supplying 60% of the EU's total renewable energy usage, mostly for the heating and cooling sector. In 2020, wind and hydropower accounted for the highest share of electricity [27] generated from renewable sources (36% and 33% respectively) whilst the rest comes from solar power (14%), solid biofuels (8%) and other sources (8%). Solar power provided only 1% in 2008 and is the fastest-growing energy source in the EU [27]. The new solar strategy and REPowerEU plan [29] entail doubling annual solar energy generation by 2025 and quadrupling it by 2030 (compared to 2020 levels). Wind energy is expected to continue to contribute the largest share of renewable electricity generation and a larger share of total electricity generation, as renewables could provide 50% of total electricity generation by 2030 [63]. Hydropower is also expected to continue to play a significant role due to its flexibility and storage potential. Offshore renewable energy, from sources such as wind, wave and tidal, is a potential cornerstone of the clean energy transition in the EU. Developing the full potential of Europe's offshore wind energy [16] is among the EGD's main energy-related objectives.

The next sub-sections describe in detail the challenges posed for biodiversity and ecosystems by specific elements of renewable energy expansion.

2.1.3.1 Bioenergy

This section is devoted to the challenges for biodiversity and ecosystems posed by the production and expansion of bioenergy (biofuels and woody biomass), as well as the EU policies addressing these issues.

2.1.3.1.1 The context

Bioenergy is the form of renewable energy with the highest potential impact on biodiversity. Recent studies [4,5,6] comparing the biodiversity footprints of three major renewable energy options (bioenergy, wind and solar) under various future scenarios show that, in all scenarios, bioenergy conflicts most with biodiversity protection due to its high potential in key biodiversity areas: half of global bioenergy production potential is located in top biodiversity areas, and three quarters of this falls on unprotected land. The overlap between high bioenergy potential and top biodiversity areas [5] was found to be highest for Central America (86%) and about 40% in other continents, including Europe. Many studies indicate that the benefits of bioenergy for global power consumption are overturned [5] by its dramatic environmental costs due to its much higher land requirements per energy unit.

2.1.3.1.2 Biofuels

While biofuels play an important role in the EU's GHG emission reduction targets for the transport sector, their production typically takes place on cropland [64] previously used for growing food or feed. Biofuel feedstock cultivation affects biodiversity [65] both directly and indirectly via land-use change, overexploitation, pollution, invasive species and climate change. Direct impacts ensue from habitat conversion for energy crops. A recent (2021) data synthesis from 116 sources showed that local species richness and abundance [66] were respectively 37% and 49% lower at sites planted with first-generation biofuel crops than at sites with primary vegetation. Second-generation or advanced biofuels also had significant – though lower – impacts, with species richness and abundance lowered by 19% and 25%.

Indirect impacts result from displacement of food and feed production, leading to the extension of agricultural land into natural habitats such as forests, wetlands and peatlands. This process of indirect land use change (ILUC) [67] threatens both biodiversity and climate change as it releases CO_2 stored in trees and soil, and can cancel the emissions reductions resulting from biofuel deployment.

EU policies on biofuels

The EU Biodiversity Strategy for 2030 [11] recommended that the use of food and feed crops for energy production – whether produced in the EU or imported – be minimised.

The EU's recast Renewable Energy Directive (REDII, 2018) [28] raised the target for the share of renewable energy used in transport to 14% by 2030, while also strengthening sustainability criteria for its use: it stipulates that production of agricultural raw material for biofuels, bioliquids and biomass, and the incentives REDII provides to promote their use, should not negatively impact biodiversity. It specifies no-go areas for agricultural biomass: bioenergy cannot be directly produced from land that was, at any time after 2008, classified as highly biodiverse grassland, primary forest, highly biodiverse forest, or protected areas.

To address the ILUC issue, REDII regulates the use of high ILUC-risk biofuels, bioliquids and biomass fuels. EU countries will still be able to use (and import) these fuels, but not to include them towards fulfilling their renewable targets. These limits impose a freeze equivalent to 2019 levels for the period 2021-2023, gradually decreasing thereafter to zero by 2030. Fuels certified as low ILUC-risk are exempted from these limits. For the implementation of this approach, the EC adopted the Delegated Regulation on indirect land-use change (2019) [68], which lays down provisions to identify high ILUC-risk biofuels, bioliquids and biomass fuels, and sets out criteria to certify those with low ILUC-risk. It also adopted the accompanying report on the status of production expansion of relevant food and feed crops worldwide [69] based on the best available scientific data. Specific rules and guidance for certifying low ILUC-risk biofuels, bioliquids and biomass fuels have been included in the Implementing Regulation on sustainability certification [70], adopted by the EC in June 2022.

In July 2021 the European Commission proposed the revision of RED II [71] under the “Fit for 55” package, which aims to deliver the 2030 target of the European Climate Law. Under the revised Renewable Energy Directive (REDIII) [30] adopted in October 2023, the Member States can choose, for the transport sector, between a considerably increased target of 29% of renewables in final energy consumption by 2030 and a target of reducing GHG intensity by 14.5% up to 2030. Expressing the transport target in terms of GHG intensity reduction is expected to stimulate innovation and increase the use of more cost-effective and high-performance fuels. In order to minimise associated environmental impacts such as pressure on land and biodiversity, the new legislation further promotes a gradual shift away from conventional biofuels to advanced biofuels [64]. Typically produced from non-recyclable waste and residues, advanced biofuels do not directly compete with food or feed production. This is also the case for renewable fuels of non-biological origin (RFNBOs), which include renewable gaseous and liquid fuels that do not rely on biomass. REDIII sets a binding sub-target for the combined share of advanced biofuels and biogas and RFNBOs of 5.5% in 2030, of which at least 1% needs to be supplied by RFNBOs.

2.1.3.1.3 Woody biomass

High worldwide demand for wood-based biomass is threatening biodiversity via more intensive forestry, risk to PAs and primary forests, burning of whole trees, and new tree plantations that do not support the same range of species, thus raising serious concerns for the sustainability of biomass consumption [19].

In the EU, the overall use of wood-based biomass has increased by 20% since 2000. It currently accounts for 60% [19] of total renewable energy consumption, and the amount used for energy increased by about 87% between 2000 and 2013. Thereafter, it has increased at a slower pace, and is projected to continue increasing

[72] in amount, though its share in total renewable energy production might decrease by 2030. The increased renewable energy target of at least 42.5% aiming to 45% can additionally impact the use of woody biomass. The EU's bioenergy production is currently based on 49% secondary wood (forest industry by-products and recovered post- consumer wood). Primary wood constitutes between 37% and 51% of all woody biomass used for energy in the EU. Reported statistics account for 37% (stemwood, treetops, branches, etc.) while the remaining 14% is uncategorised, but analysis of woody biomass flows [72] indicates that it is likely to be primary wood. Wood-based biomass can contribute to a collective solution to both climate change and biodiversity crises – but only if produced sustainably and used efficiently. This is especially critical considering that Europe's forest ecosystems are not in good condition [72].

EU policies on woody biomass

The Renewable Energy Directive (RED) for the 2010–2020 period applied sustainability criteria only to biofuels and bioliquids. The recast Renewable Energy Directive (REDII, 2018) [28] extended their scope to solid biomass and biogas used in large-scale heating/cooling and electricity installations. REDII also introduced new sustainability criteria for forest biomass to ensure compliance with sustainable forest management laws and principles, including minimisation of biodiversity impacts and proper accounting of the carbon impacts of bioenergy in the land use, land-use change and forestry (LULUCF) sector. The REDII definition of environmentally sustainable bioenergy focuses on biodiversity conservation and climate change mitigation. Additionally, in 2020 the EU Biodiversity Strategy for 2030 [11] recommended that the promotion of advanced biofuels produced from waste and residues be applied to all forms of bioenergy, and the use of whole trees for energy production be minimised. The new EU Forest Strategy (July 2021) [19] stated that bioenergy will continue to play a notable role in the energy mix if biomass is produced sustainably and used efficiently, in line with the cascading principle and taking into account the Union's carbon sink and biodiversity objectives as well as the overall availability of wood within sustainability boundaries.

Whilst REDII was a step forward in ensuring the sustainability of EU bioenergy production, recent scientific evidence and the EU's increased climate and biodiversity ambition call for further safeguarding the sustainability of forest-based bioenergy. The 2021 JRC report on the use of woody biomass for energy production in the EU [69], initiated in this connection, identifies several potential improvements to minimise damaging pathways for biomass provision. Among its sustainability criteria, REDII specified no-go areas for agricultural biomass, but these did not apply to forest biomass, except for the PAs criterion. The report strongly recommends expanding such land criteria to forests to further ensure that forest biomass for energy is not associated with destructive afforestation pathways, such as those on high-nature value grasslands or anthropogenic heathlands, and forbidding the sourcing of wood from plantations on converted old-growth primary forest. The report also reveals considerable inconsistencies in reporting forest-related data and emphasises the importance of improving their availability and quality, in particular relating to the energy use of wood. It compares the impacts of various forest management strategies and pathways on both biodiversity and climate change. The win-win pathways identified include slash removal below the landscape threshold and afforestation of former arable land with mixed or naturally regenerating forests. Lose-lose pathways include removal of coarse woody debris and low stumps, and conversion of primary or natural forests into plantations. However, there are also trade-offs or win-lose pathways: climate mitigation strategies that potentially compromise biodiversity. These include afforestation of natural grassland and anthropogenic heathland with plantations, monoculture plantation on former cropland, and slash removal above the landscape threshold.

Many of the above considerations were incorporated in the revised Renewable Energy Directive (REDIII) adopted in October 2023 [30]. The directive sets out additional concrete safeguards, including further strengthened sustainability criteria for bioenergy, extending their scope of application to include forest biomass and enlarging no-go areas for sourcing: prohibiting the sourcing of forest biomass from primary forests and limiting it in highly biodiverse forests and grassland and in heathland and peatlands. Further elements are added to minimise the negative impact of harvesting on soil quality and biodiversity.

However, bioenergy-related GHG emissions are not counted in the energy sector, but in the LULUCF (land use, land use change and forestry) sector. REDII as well as REDIII thus assume zero emissions at the point of biomass combustion. Furthermore, imported biomass and biofuels do not add emissions in the LULUCF sector in the EU, but can be significant drivers of deforestation on a global level. The LULUCF Regulation [73] (2018) states that the sector, including agricultural land, has a direct and significant impact on biodiversity and ecosystem services, and underscores the importance of coherence with the EU-BDS 2030. However, the provisions under the LULUCF Regulation do not safeguard against negative impacts from enhanced bioenergy use [74] or other land-use policies on biodiversity. The regulation thus needs additional safeguards, such as the legally binding EU nature restoration targets in EU-BDS 2030 and enhanced sustainability criteria under REDIII. The Commission proposal (2021) to amend the LULUCF Regulation [75] included aligning its objectives with related policy initiatives on biodiversity and bioenergy, and merging LULUCF emissions with non-CO_2 agricultural emissions from 2031 to cover the whole land sector, which would have to achieve climate neutrality by 2035. The impact assessment accompanying the proposal [76] identified significantly decreasing net LULUCF removals as a major problem, driven by natural disturbances such as forest fires, heatwaves, drought, pests, etc. that are exacerbated by climate change and biodiversity loss, and will in turn affect the functioning of ecosystems. It also identified missed opportunities to strengthen synergies between climate action and biodiversity action due to challenges in monitoring and reporting climate information on areas of special importance for biodiversity. The revised LULUCF Regulation [77] was adopted in April 2023 for the period up to 2030. It aims to reverse the declining trend in LULUCF removals and sets an EU-wide target of -310 million tonnes of CO_2 equivalent of net removals by 2030, along with improved monitoring, reporting and verification and simplified accounting rules.

2.1.3.2 Solar PV, wind, hydropower and other RE sources

This section is devoted to the challenges for biodiversity and ecosystems posed by the expansion of installations for renewable energy production from solar PV, wind, hydropower and other RE sources, as well as the EU policies addressing these issues.

2.1.3.2.1 The context

The conflict from overlap between energy production potential and biodiversity conservation appears lower for wind and solar photovoltaics (PV) than for bioenergy: about one third of their global potential [5] is located within top biodiversity areas (with some exceptions like Central and South America, where it is higher). However, another recent study [3] showed that the overlap between existing solar/wind/hydropower facilities and conservation areas is by far the highest in Western Europe, with over 1200 out of a global total of 2200 facilities operating within protected areas (PAs), Key Biodiversity Areas (KBAs), and wilderness areas. On the other hand, life-cycle analyses [6] show that solar and wind energy deployment is far less environmentally damaging overall than using fossil fuels. The expansion rate of hydropower is likely to decline globally, but its share in total renewable energy generation remains one of the largest, and 28% of planned global hydropower is within PAs.

Hydropower has built-in energy storage capacity and fast response time, which allows it to compensate for sudden fluctuations in supply or demand of other renewable sources (such as solar and wind power). However, dams can significantly harm local, downstream and upstream biodiversity [78]. They alter river morphology and habitats, water flow regimes and ecological flows, seasonal flood cycles, water quality and temperature. They can block species migration and dispersal, and disrupt sediment dynamics.

Ultimately, solar power could provide substantial benefits compared to environmental costs [4,5], if energy transport and/or storage limitations are gradually lifted. It is also one of the cheapest sources of electricity [79] available. However, in the case of a future economic scenario constrained by local energy demand, without long-distance transmission, the threat to biodiversity from solar and wind could reach a level comparable to that of bioenergy. Under the unconstrained (optimistic) energy scenario, utilizing only 1% of land outside of top biodiversity areas [5] for solar production could meet the total global power consumption, whereas bioenergy or wind energy would still contribute less than 10% to global consumption. All studies considered do caution against full adoption of utility-scale solar development without adequate understanding of environmental ramifications. Utility-scale solar installations can be massive, with significant land requirements. Habitats transformed into solar farms will suffer from a wide range of impacts [80] such as reduced vegetative cover, soil degradation, and impaired water quality. They can create a new built environment or microclimate, causing habitat degradation [80] by altering sun exposure, moisture and surface temperature, and possibly disrupting photosynthesis [4].

All three types of installations (hydro, solar, and wind) can impact species directly [81]. Several vulnerable species groups like vultures, bustards, cranes, bats, raptors and many migratory species are at risk from collision with wind turbines or electrocution from energy transmission lines (though fossil fuels pose a much greater – if less obviously visible – threat to birds and bats, mainly through pollution and climate change). Contact with hydropower turbines and other machinery, as well as pressure fluctuations, can harm fish and other river species. Supporting infrastructure, including transmission lines and roads, may facilitate hunting, indirect habitat loss, fragmentation and invasive species dispersal, resulting in impacts that extend far beyond their immediate physical footprint [3]. Offshore wind installations can pose a threat to marine mammals, sea turtles, and some fish species due to construction noise and collisions with associated vessels, while habitat alteration affects species of the sea floor. Emerging technologies such as floating solar and wind – and renewable energy development in deeper offshore waters – are gathering pace, and the risks need to be properly researched.

The risks for nature need to be taken into account right from the earliest stages in the siting and design [81] of RE installations – and the associated infrastructure such as access roads and powerlines. Analyses suggest [3] that strict protected PAs provide more effective protection against RE development than less strict (categories V and VI) and non-categorised PAs. Other sensitive breeding areas, key biodiversity areas and species migration routes also need to be excluded. Building a strong evidence base [82] can help reduce the trade-offs between RE expansion and biodiversity. Studies indicate that planned RE deployment would not significantly affect area-based conservation targets, if done with appropriate policy and regulatory controls [83]. Fortunately, the abundance of solar and wind energy means that there is often flexibility in project siting, allowing the use of already converted or disturbed land or offshore locations away from areas of high sensitivity. By contrast, large-scale hydropower is often highly constrained by location.

A recent IUCN report [81] recommends a mitigation hierarchy consisting of sequentially and iteratively implementing four actions: avoid, minimise, restore and (if impacts could not be anticipated) offset. Early avoidance and minimisation actions are key; they include burying or rerouting power lines, infrastructure adaptation, and eliminating electrocution risks. Noise impacts in offshore installations can be minimised via strict construction protocols. New technologies offer considerable risk-minimisation potential, such as turbines able to shut down depending on bird activity and acoustic deterrents. Pro-active conservation can play a vital role: onshore wind and solar farms offer habitat-restoration and enhancement opportunities in degraded areas whilst artificial reefs around offshore turbines can enhance biodiversity and fish stocks. When offsets become necessary due to unanticipated impacts, their planning and implementation should follow best practice principles: for instance, addressing cumulative impacts on similar ecosystems by channelling resources into a single aggregated offset.

The disposal of used solar panels presents another potential concern. Since they were first introduced in the 2000s, tonnes of solar panels are reaching the end of their lifespan. They contain heavy metals such as lead and cadmium, which can be hazardous for ecosystems as well as hard to extract, making recycling difficult and costly. Costs are currently 10 to 30 times higher for recycling than for dumping panels in landfills, which is where they could end up – or exported to developing countries, which lack the infrastructure and regulations for proper disposal. The JRC report (2016) [84] expects their disposal to become a relevant environmental issue over the coming years. It points to the lack of scientific research on the end-of-life phase of solar panels. Projections by the International Renewable Energy Agency (IRENA) anticipate large amounts of waste from solar panels by 2030, possibly reaching 78 million tonnes [85] by 2050, assuming customers will keep the panels in place for their entire 30-year lifespan. However, other studies [86] predict earlier replacements, indicating a much higher level of waste. The main prospective solutions currently being investigated are: (i) new techniques to make recycling cost-effective [86] by extracting valuable materials (like silver and silicon) contained in the panels, and (ii) making the manufacturing process cleaner (purifying silicon for cells and, more recently, replacing it with perovskite cells based on non-toxic metals). While the latter does not address the disposal of currently accumulating panels, techniques for their cost-effective recycling as part of a circular economy are improving significantly.

2.1.3.2.2 Relevant EU policies on solar PV, wind energy, hydropower and other renewable energy sources

Solar power is the fastest-growing energy source in the EU [27]. It can be rolled out rapidly, offers substantial climate benefits, and is one of the EU's cheapest energy sources: the cost of solar power has decreased by 82% [79] over the last decade. As part of the REPowerEU plan [29], the EU Solar Energy Strategy [79] (2022) aims to double annual solar energy generation by 2025 (compared to 2020) and quadruple it by 2030. The strategy foresees that the required utility-scale expansion will increasingly face competing uses of land and public acceptance challenges. It calls for MS to undertake a mapping exercise to identify appropriate locations for renewable energy installations and go-to areas [88] with simple and fast permitting procedures, while limiting the impact on other uses of land and ensuring environmental protection. To this end it recommends innovative forms of deployment and multiple use of space. The European Solar Rooftops Initiative [79] is one of its flagship initiatives. Rooftops have housed most solar installations so far, but huge untapped potential remains. According to some estimates [89], rooftop installations could provide almost 25% of EU electricity. Considered low-hanging fruit, they can be deployed rapidly, shield consumers from volatile prices, and avoid conflicts with nature. Beyond rooftops, the solar strategy points to other opportunities for solar energy generation provided by buildings, such as building-integrated PV, whose potential remains to be unlocked.

Other innovative solutions mentioned include repurposing former industrial or mining land for solar energy installations; using water surfaces with minimal environmental impacts such as artificial lakes created by hydroelectric dams; deploying agri-voltaics [90] (PV systems in agriculture can contribute to crop protection and yield stability, a potential win-win for renewables, agriculture and sustainability [91]); and installing solar panels along highways or railway tracks. The EU-BDS 2030 specifically mentions solar-panel farms providing biodiversity-friendly soil cover as a win-win solution for energy and biodiversity. Any intervention on water bodies must respect the conditions set out in the Water Framework Directive [92] and the Marine Strategy Framework Directive [93]. Best practice measures to mitigate harmful impacts of solar farms on EU natural habitats and species [80] focus on appropriate site planning, as well as enhancing biodiversity values on solar farms, and improving boundary features to enable wildlife mobility.

Since 2012, PV waste has been formally included [94] as Waste of Electrical and Electronic Equipment within the recast WEEE Directive [95], which requires producers and importers of PV panels to take responsibility for their end-of-life management. The regulation has started to come into force among EU MS. Several European projects [96] have been launched to reduce disposal hazards, as well as optimising value towards supporting a circular economy, by extracting high-purity valuable materials from dead PV panels. These include CABRISS [97] and Photorama [98] co-funded by Horizon 2020, ReProSolar [99] co-funded by Horizon Europe, and FRELP [100], co-funded by the European LIFE programme (for details, see Section 2.2 covering these and other EU-supported projects and initiatives). FRELP is also discussed in the 2016 JRC report analysing material recovery from silicon PV panels [94].

Over the coming years, wind power is expected to retain its position as top provider (36%) of electricity from renewable sources [101] in the EU. A significant expansion of wind energy (offshore plus onshore) is thus foreseen, in light of the significantly larger share of renewables expected in the energy mix by 2030. Offshore RE (wind, wave and tidal) avoids some of the challenges faced by onshore renewables, such as natural obstructions or competition for space with other human activities. The EU Offshore Renewable Energy Strategy (2020) [102] assigns it an important role in attaining climate targets. The required scale-up of the offshore wind industry to meet the 55% GHG reduction target by 2030 is estimated to require less than 3% of European maritime space. It can thus be compatible with the EU-BDS 2030, which calls for expanding the EU's network of marine protected areas from 11% to 30% of EU maritime space, of which a third must be strictly protected (only 1% was in 2020). The EU-BDS 2030 specifically mentions ocean energy and offshore wind as potential win-win solutions for climate and biodiversity. Offshore RE development has to comply with EU environmental legislation and integrated maritime policy including the Habitats [103] and Birds [104] Directives, the Marine Strategy Framework Directive [93], the Maritime Spatial Planning Directive [105], and the EU-BDS 2030 [11]. Maritime spatial planning will be crucial for ensuring that designated sea spaces are compatible with biodiversity protection and fulfilling the obligations to reach good environmental status enshrined in the Marine Strategy Framework Directive.

Hydropower accounted for 33% of EU renewable electricity production in 2020 and 17% of total EU electricity production. It is foreseen to continue to play an important role [106], with thousands of new plants planned or under construction. Its flexibility and storage options [107] help stabilise the EU electricity system by integrating variable RE production from other sources such as solar and wind. At the same time, dams and other barriers have significantly impacted EU freshwater ecosystems [108] and are a key driver of the collapse of freshwater migratory fish populations in Europe, estimated at 93% since 1970. 33% of planned hydropower in Europe is within PAs.

Key pieces of EU legislation addressing environmental impacts of hydropower [78] include the Water Framework Directive (WFD) [92], the Floods Directive [109], the Nature (Habitats [103] and Birds [104]) Directives, and the Environmental Assessments Directives [110]. Environmental impacts include changes that can affect wildlife and river morphology, causing a fragmentation of the river system. In 2020, the EU-BDS 2030 emphasised the need for greater efforts to achieve WFD objectives of restoring freshwater ecosystems and natural river functions. It set a target of removing river barriers [108] to enable at least 25,000 km of free-flowing rivers in the Union by 2030, thus facilitating the passage of migrating fish and improving water and sediment flows. This target was made legally binding under the proposal (2022) for a Nature Restoration Law, and in the revised text provisionally agreed with the Council and the European Parliament and formally adopted by the Parliament in February 2024. It focuses on removing obsolete barriers [108], such as dams no longer useful for hydropower generation.

Though closely linked with broadly similar objectives, the WFD and Nature Directives have distinct specific aims. Whilst the WFD aims at "good ecological status" of water bodies, the Nature Directives aim at a favourable conservation status of specific species across their natural range. Since reaching good ecological status is not necessarily sufficient for reaching favourable conservation status, the WFD explicitly recognises the need for additional conservation measures: it states that 'where more than one of the objectives relates to a given body of water, the most stringent shall apply'. The Commission's guidance document on hydropower in relation to EU nature legislation (2018) [78] states that these additional needs should be included in the WFD river basin management plan via specific provisions regarding PAs. It cites several good practice examples of mitigating effects and applying ecological restoration measures to hydropower, as well as of integrated planning approaches. However, the European overview of the second river basin management plans (2021) [111] concluded that these additional needs for protecting water-dependent habitats and species were unknown for 44% of PAs under the Nature Directives, while work to determine the needs for another 13% was still ongoing. Specific water objectives had been set only for 17% of PAs under the Nature Directives.

The Commission's REPowerEU plan (2022) calls on MS to swiftly map, assess, and ensure suitable land and sea areas that are available for renewable energy projects [29], commensurate with contributions towards the revised 2030 renewable energy target, and other factors including the targets of the EU-BDS 2030. In identifying go-to areas [88], MS are required to prioritise artificial and built surfaces, and degraded land not usable for agriculture, and to exclude Natura 2000 sites and nature parks and areas, as well as bird migratory routes. They are to use all appropriate tools and datasets, including wildlife sensitivity mapping, to identify areas where renewable energy plants would not have a significant environmental impact. To support MS in identifying such "renewables go-to areas" for the rapid deployment of new RE installations, the JRC's Energy and Industry Geography Lab [112] has developed (2022) a visual tool [113] that consolidates information on a wide range of energy and environmental factors.

2.1.3.3 Batteries and mining

This section is devoted to the challenges for biodiversity and ecosystems posed by the envisaged increase in production of batteries for storing renewable energy, as well as the EU policies addressing these issues.

2.1.3.3.1 The context

Batteries for electric vehicles and storage of intermittent renewable energy (from sources such as wind and solar) play an important role in climate change mitigation actions. Global battery demand is expected to increase 14-fold by 2030, with the EU accounting for 17%. Batteries are of strategic importance [114] for the EU's transition to a climate-neutral economy. Critical raw materials embedded in batteries include antimony in lead-acid batteries; rare earth elements in nickel-metal hydride batteries; and lithium, cobalt and natural graphite in lithium-ion batteries. For electric vehicle batteries and energy storage, it has been estimated that the EU will need [114] up to 18 times more lithium and 5 times more cobalt by 2030, and nearly 60 times more lithium and 15 times more cobalt by 2050, compared with the current supply to the whole EU economy.

2.1.3.3.2 Extraction of raw materials

The mining and extraction of these raw materials has been associated with adverse environmental impacts [114] (e.g. local water, soil and air pollution; ecosystem and landscape degradation), apart from human rights violations. A recent study [112] concluded that mining potentially influences 50 million km^2 of the earth's land surface, with 8% coinciding with PAs, 7% with KBAs, and 16% with remaining wilderness. Most mining areas (82%) target materials for renewable energy production, and areas that overlap with PAs and remaining wilderness contain a greater density of mines [115] compared to the overlapping mining areas that target other materials. Threats to biodiversity from mining activities will increase as more mines target materials for renewable energy production and, without strategic planning, these new threats to biodiversity may surpass those averted by climate change mitigation. Cobalt is a case in point: nearly half the world's cobalt reserves lie in the Democratic Republic of Congo (DRC), which accounts for over two thirds of global cobalt production. A recent JRC report [116] also identifies other EU suppliers of battery raw materials, raising concerns for responsible sourcing. China accounts for 47% of the EU's supplies of natural graphite and nickel, and South Africa and Brazil for 26% and 17% of EU manganese supply. Important potential impacts include those on biodiversity in Brazil and on water risk and environmental performance in South Africa. The report also identifies future potential risks in the Philippines and Indonesia (nickel), Mozambique and Tanzania (graphite) and Bolivia (lithium).

2.1.3.3.3 End-of-life handling

More than 1.9 million tonnes of waste batteries [114] are generated annually in Europe. Collection and recycling rates, as well as environmental and health impacts, depend heavily on the battery type. Automotive lead-acid batteries have the highest collection and recycling rates: between 90% and 100% of lead is recovered in the EU. Portable batteries have much lower collection rates: only 48% sold in the EU were collected for recycling in 2018. Large amounts of valuable resources are thus lost, and some 35 kilotonnes of portable batteries end up in municipal waste annually with possible leaching of hazardous substances. The remainder is either stored, exported outside the EU in used products, or ends up in e-waste recycling.

2.1.3.3.4 Relevant EU policies on battery use

In October 2017 the Commission set up the European Battery Alliance to support the scaling up of innovative solutions and manufacturing capacity in Europe. In May 2018, as part of the third 'Europe on the move' mobility package, it adopted a dedicated strategic action plan on batteries, with a range of measures covering raw materials extraction, sourcing and processing, battery materials, cell production, battery systems, reuse and recycling. Building on this, the proposal for a Regulation on Batteries and Waste Batteries [117] adopted in December 2020 is geared towards modernising EU legislation on batteries in order to ensure the sustainability and competitiveness of EU battery value chains. One of the three groups of problems it addresses are risks currently not covered by EU environmental law. These include: (i) a lack of transparency on sourcing raw materials; (ii) hazardous substances; and (iii) the untapped potential for offsetting the environmental impacts of battery life cycles. The new regulation [118], adopted by the European Parliament and the Council in July 2023, introduces mandatory requirements for sustainability and end-of-life management, and due diligence obligations for economic operators as regards the sourcing of raw materials.

2.1.4 Biodiversity and climate change mitigation: geoengineering and negative emission technologies

This section describes the potential impacts of deploying geoengineering and negative emission technologies on biodiversity and ecosystems, as well as the relevant EU policies.

2.1.4.1 The context

The IPCC special report "Global warming of 1.5°C" (2018) [8] states that all analysed pathways limiting warming to 1.5°C with no or limited overshoot use carbon direct removal (CDR) to some extent to neutralize emissions from sources for which no mitigation measures have been identified and, in most cases, also to achieve net negative emissions to return global warming to 1.5°C following a peak. The IPCC Sixth Assessment Report (2022) [7] states that the deployment of CDR to counterbalance hard-to-abate residual emissions is unavoidable if net zero GHG emissions are to be achieved. Apart from reforestation and afforestation (covered in Sections 2.1.2 and 2.1.3.1), the main CDR options are geoengineering or negative emission technologies (NETs) involving Carbon Capture and Storage (CCS): Bioenergy Carbon Capture and Storage (BECCS) and Direct Air Carbon Capture and Storage (DACCS). BECCS involves capture and storage of CO_2 emitted by bioenergy use whilst DACCS involves capture of CO_2 from ambient air followed by its storage. Other options such as mineralisation and enhanced weathering of rocks and ocean fertilisation are also considered. NETs were originally proposed as stopgap measures over the interim period before sufficient emissions cuts could be achieved. However, in the absence of adequate progress on the latter, their long-term or indefinite deployment is being increasingly mainstreamed in IPCC mitigation pathways.

CCS involves capture of CO_2 emitted by fossil fuel and biomass fuel use, followed by compression, transport via pipeline and high-pressure injection into near-depleted oil and gas fields, saline aquifers, or ocean beds. It is currently not commercially viable [119] except in combination with enhanced oil recovery (EOR) – making it questionable as a climate change response, though interesting for the fossil fuel industry. Another motivation for its deployment is to reduce stranded fossil fuel infrastructure [7]. Carbon leakage remains a major concern: during transportation [120] or along faults and fissures after injection [119], thus increasing emissions later. Environmental impacts [121] such as water depletion [122] toxicity and acidification [123], and freshwater eutrophication [124] have also been indicated.

BECCS (Bioenergy CCS) has taken centre-stage in recent years as a key CDR option and integral part of IPCC mitigation pathways. Virtually all climate change models projecting a future consistent with the Paris Agreement assume a key role for BECCS, which involves large-scale biofuel crop cultivation. Important studies [125] have indicated that large-scale BECCS deployment is likely to steer us closer to the planetary boundaries for freshwater use and lead to further transgression of the boundaries for land-system change, biosphere integrity and biogeochemical flows, implying large risks for biodiversity, nutrient and water cycles. Other studies [126] indicate that BECCS could seriously compromise biodiversity and food security. While citing BECCS as integral to all widely accepted pathways limiting warming to 1.5°C, the IPCC sixth assessment report Climate Change 2022: Impacts, Adaptation and Vulnerability [122] also cautions that its large-scale use could damage ecosystems directly or through increasing competition for land, with substantial risks for biodiversity as well as profound implications for water resources. Moreover, within safe boundaries BECCS is estimated to only compensate for less than 1% of current global GHG emissions. In addition, BECCS shares the hazards of the transport, injection and storage phases of CCS. However, energy and fossil fuel companies and providers are heavily investing in CCS/BECCS; these include Eurelectric [127] ExxonMobil, Chevron, BP [128], Shell [129] and other European energy companies [130].

Other CDR options or NETs considered in IPCC scenarios, such as ocean fertilisation and enhanced weathering, also have serious potential consequences for biodiversity. Ocean fertilisation could lead to nutrient redistribution, restructuring of ecosystems, enhanced oxygen consumption and acidification in deeper waters. [7]. It could cause toxic algal blooms and marine dead zones from plankton die-off. Enhanced weathering involves mining and large-scale surface dumping of olivine.

Apart from CDR or NETs, another category of geoengineering technologies involves solar geoengineering or solar radiation management (SRM) that lowers atmospheric heat by bouncing sunlight back into space before it reaches the earth's surface. This can be achieved by injecting aerosol particles [131] into the stratosphere or by modifying clouds and/or surface albedo to reflect sunlight. All SRM techniques modify the planet's radiative balance and are likely to alter the hydrological cycle and mess with weather patterns, disturbing ecosystems and biodiversity in unpredictable ways. It has been estimated that – even if SRM were used only temporarily – the long atmospheric life of CO_2 could lead to a quick and massive warming effect on abrupt termination [132] and have a catastrophic effect on biodiversity [133]. While SRM is not yet specifically included in official mitigation pathways, lack of action on actual emission reduction could force its future deployment.

The potential threats posed by large-scale geoengineering deployment for biodiversity could be unpredictably greater than those from renewable energy expansion, further emphasising the urgent need for careful coordination between conservation efforts and RE implementation. Moreover, reliance on geoengineering could hinder a green transition by leading to technology lock-in, or by locking society into a high-temperature pathway if it is unsuccessful [134] at reducing global warming to the extent assumed, or by normalising a carbon budget deficit via offsetting [135]. Many scientists have expressed strong reservations and made multiple calls for a more holistic assessment of NETs [136].

2.1.4.2 Relevant EU policies on negative-emission technologies

The adoption of the European Green Deal, the Climate Law and the subsequent proposals to enhance energy and climate targets for 2030 have made CCS technologies an important part [137] of the EU decarbonisation effort. The Climate Law states that solutions based on CCS can play a role in decarbonisation, especially for the mitigation of process emissions in industry. CCS is considered key to tackling inherent CO_2 emissions from energy-intensive processes in industries [138] such as cement, iron and steel, aluminium, pulp and paper, and refineries. Its contribution via BECCS and DACCS is also included, as is its potential as a platform for low-carbon hydrogen production.

The Commission Communication (2021) on Sustainable Carbon Cycles [139] lists key actions to support industrial capture, use and storage of CO_2. The communication also proposes a way forward to certify carbon removals towards establishing sustainable and climate-resilient carbon cycles. The key actions include developing methodologies to quantify climate benefits of sustainably produced building materials with carbon storage potential, an integrated EU bioeconomy land-use assessment, better support for industrial removals with the Innovation Fund, Horizon Europe support in the work programme 2023/24, a study on the development of the CO_2 transport network, update guidance for the CCS Directive, and organising an annual carbon capture, utilisation and storage (CCUS) forum. The Circular Economy Action Plan (2020) [23] had also mentioned a forthcoming framework for the certification of carbon removals to incentivise uptake and increase circularity of carbon, in full respect of the biodiversity and zero-pollution objectives. In November 2022 the Commission followed this up [140] with a proposal for a Regulation establishing a Union certification framework for carbon removals [141], which seeks to (i) ensure the high quality of carbon removals in the EU and (ii) establish an EU governance certification system to avoid greenwashing by correctly applying and enforcing the EU quality framework criteria in a reliable and harmonised way across the Union. The quality criteria for carbon removal certification involve following quantification rules with specific baselines, demonstrating additionality, ensuring long-term storage, and supporting sustainability objectives on climate change, biodiversity, pollution and a circular economy. A provisional agreement with the European Parliament and the Council on a revised text was reached in February 2024.

A report (July 2022) from an EU-supported project on CCS in a biodiversity and land use perspective [142] notes that the impact of CCS on land use and biodiversity requires thorough investigation. Its assessment of the biodiversity and land use impacts of CCS led to detailed recommendations on EU deployment of CCS/BECCS/DACCS. Its recommendations include making biodiversity and other ecosystem sustainability considerations a pre-requisite for the production and use of biomass for industrial or energy purposes. On CO_2 capture, its recommendations include systematically conducting a comprehensive life-cycle assessment of CCS/BECCS/DACCS projects, including a full set of environmental impact indicators, beyond GHG emissions, to assess impacts on land use and biodiversity. Regarding CO_2 transport and storage, its recommendations include minimising corridors, actively monitoring and restoring disturbed land with native species, and ensuring that strict measures are taken by operators to prevent CO_2 leakage during transport and storage. While indicating that northern Europe has optimal conditions for the deployment of BECCS plants, the report concludes that – for the same energy yield – renewable hydrogen and electricity from wind turbines have lower land requirements than biomass, indicating a lower impact on biodiversity.

2.2 EU-supported projects and initiatives on biodiversity, climate change and energy

The projects and initiatives listed below are mainly within Europe; global EU-supported projects are listed in another report in this series [9] that covers global biodiversity governance.

2.2.1 RTD (Research & Innovation) projects

A large number of Research & Innovation (RTD) programmes under FP7 (2007-13)[2] and Horizon 2020 (2014-20)[3] have supported projects relating to biodiversity, climate change and energy. Calls under the first two phases of the new Horizon Europe (2021-27)[4] are ongoing and have been listed in the HE Work programme for 2021-22 and the HE Work programme for 2023-24.

2.2.1.1 FP7 (2007-2013) programmes covering biodiversity, climate change and energy

Specific Programme "Cooperation": Environment (including Climate Change) (FP7-Environment; funding € 1.9 billion) aimed at improving the sustainable management of environmental resources by advancing knowledge on interactions between the climate, biosphere, ecosystems and human activities via multidisciplinary research. Among the areas addressed were biodiversity conservation and sustainable management, environmental pressures, marine environment management, earth and ocean observation and monitoring, and nature restoration.

Specific Programme "Cooperation": Food, Agriculture and Biotechnology (FP7-KBBE; total funding € 1.9 billion) aimed at advancing knowledge on the sustainable management, production and use of biological resources (microbial, plant and animal) towards safer, healthier, eco-efficient and competitive products and services for agriculture, fisheries, feed, food, health, forest-based and related industries. New renewable energy sources were covered under the concept of a European knowledge-based bio-economy. The programme included research activities on sustainable non-food products and processes to develop improved crops and forest resources, feedstocks, and biomass technologies for energy and environment.

2.2.1.2 Horizon 2020 (2014-2020) programmes covering biodiversity, climate change and energy

Pillar III (SOCIETAL CHALLENGES): "Climate action, Environment, Resource Efficiency and Raw Materials" (H2020-EU.3.5; funding € 3.1 billion) aimed to achieve a resource- and water-efficient and climate change-resilient economy and society, protect and sustainably manage natural resources and ecosystems, and ensure a sustainable supply and use of raw materials. Among its actions most relevant for biodiversity, climate change and energy are "Fighting and adapting to climate change" (H2020-EU.3.5.1); "Protecting the

[2] Seventh framework programme of the European Community for research and technological development including demonstration activities (FP7). https://cordis.europa.eu/programme/id/FP7

[3] Horizon 2020 - The EU Framework Programme for Research and Innovation. https://ec.europa.eu/environment/integration/research/2020_en.htm

[4] Horizon Europe – Research and innovation funding programme until 2027. https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe_en

environment, sustainably managing natural resources, water, biodiversity and ecosystems" (H2020-EU.3.5.2) which included the AMBER project (EU co-funding € 6.0 million) on adaptive river-barrier management in the context of hydropower; "Ensuring the sustainable supply of non-energy and non-agricultural raw materials" (H2020-EU.3.5.3), which included the Photorama project (EU co-funding € 8.4 million); "Enabling the transition towards a green economy and society through eco-innovation" (H2020-EU.3.5.4), which included the CABRISS project (EU co-funding € 7.8 million); and "Developing comprehensive and sustained global environmental observation and information systems" (H2020-EU.3.5.5). The Photorama project (2021-24) will build an automated pilot facility to disassemble PV panels, recover most of their mass, and process those materials to maximum purity. It builds on expertise generated in the earlier CABRISS project (2015-18) pioneering a circular economy based on recycled, reused and recovered indium, silicon and silver for PV and other applications.

Pillar III (SOCIETAL CHALLENGES): "Secure, clean and efficient energy" (H2020-EU.3.3; funding € 6 billion) aimed to make the transition to a reliable, affordable, publicly accepted, sustainable and competitive energy system, aiming at reducing fossil fuel dependency in the face of increasingly scarce resources, increasing energy needs and climate change. Among its actions most relevant for biodiversity, climate change and energy are "Reducing energy consumption and carbon footprint by smart and sustainable use" (H2020-EU.3.3.1); "Low-cost, low-carbon energy supply" (H2020-EU.3.3.2), which included the FIThydro project (EU co-funding € 5.9 million) on fish-friendly hydropower technologies; "Alternative fuels and mobile energy sources" (H2020-EU.3.3.3); "New knowledge and technologies" (H2020-EU.3.3.5); and "Market uptake of energy innovation" (H2020-EU.3.3.7).

Pillar III (SOCIETAL CHALLENGES): "Food security, sustainable agriculture and forestry, marine, maritime and inland water research, and the bioeconomy" (H2020-EU.3.2; funding € 3.9 billion) aimed to secure sufficient supplies of safe, healthy and high quality bio-based products, by developing productive, sustainable and resource-efficient primary production systems, fostering related ecosystem services and the recovery of biological diversity, alongside competitive and low-carbon supply, processing and marketing chains. Among its actions most relevant for biodiversity, climate change and energy are "Sustainable agriculture and forestry" (H2020-EU.3.2.1), "Sustainable and competitive bio-based industries and supporting the development of a European bioeconomy" (H2020-EU.3.2.4) and "Cross-cutting marine and maritime research (H2020-EU.3.2.5)."

Pillar III (SOCIETAL CHALLENGES): "Smart, Green And Integrated Transport" (H2020-EU.3.4; funding € 6.3 billion) included projects aimed at minimising transport systems' impact on climate and environment by improving quality and efficiency in the use of natural resources and fuel, and reducing GHG emissions.

Pillar I (EXCELLENT SCIENCE): European Research Council (ERC) (H2020-EU.1.1; total funding € 13.1 billion) and Marie Skłodowska-Curie Actions (H2020-EU.1.3; total funding € 6.2 billion) also include several topics relevant to biodiversity, climate change and energy. The ERC-funded projects include the project package "Frontier research for the Green Deal: Driving forward Europe's climate ambitions through innovation and transformation," and several others that cover biodiversity and renewable energy.

2.2.1.3 Horizon Europe (2021-2027) ongoing calls/programmes covering biodiversity, climate change and energy

Horizon Europe's (HE) Pillar II on Global Challenges and European Industrial Competitiveness covers biodiversity, climate change and energy as major topics mainly under Cluster 5 and Cluster 6.

The HE Work programme (2021-22) for Cluster 5 and HE Work programme (2023-24) for Cluster 5 on "Climate, Energy and Mobility" include several destinations relevant for the biodiversity, climate change and energy nexus. Particularly relevant are calls under destination 1 "Climate sciences and responses for the transformation towards climate neutrality," which cover climate change adaptation and climate services, and better understanding of climate-ecosystem interactions among its main objectives. Calls under destinations 2 to 6 focus on developing technologies for batteries, renewable energy and carbon capture towards increased efficiency and sustainability of energy, resource use and climate solutions.

The HE Work programme (2021-22) for Cluster 6 and HE Work Programme (2023-24) for Cluster 6 on "Food, Bioeconomy, Natural Resources, Agriculture and Environment" include several destinations covering topics relevant to the biodiversity, climate change and energy nexus. Particularly relevant are calls under destination 1 "Biodiversity and ecosystem services," destination 3 "Circular economy and bioeconomy sectors" and destination 5 "Land, ocean and water for climate action."

Pillar I (Excellent Science) also continues under HE. Many topics relevant to the biodiversity, climate change and energy nexus are included under its Marie Sklodowska-Curie Actions and its Research Infrastructures programme.

Pillar 3 (Innovative Europe) includes the European Innovation Council (EIC) with its Pathfinder, Transition and Accelerator actions, as well as the European Institute of Innovation and Technology (EIT). The EIC supports SMEs and research teams developing breakthrough innovations with a focus on contributing to objectives of the European Green Deal and the Recovery Plan for Europe. Its programme EIC Accelerator Challenge – Green Deal innovations for the Economic Recovery supports projects with sustainability goals, including increasing the EU's climate-change mitigation and/or adaptation ambition; supplying clean, affordable and secure energy; and preserving and restoring ecosystems and biodiversity. The EIT supported the ReProSolar project (EU co-funding € 4.8 million) on efficient recycling of end-of-life solar PV modules.

2.2.2 CINEA projects

The European Climate Infrastructure and Environment Executive Agency (CINEA)[5] runs many programmes that fund projects relevant for the topic "biodiversity, climate change and energy." These include programmes for environment and climate action such as the LIFE programme[6], and others in the energy, transport and maritime sectors.

The LIFE programme

In 2021 the Commission approved an investment package of more than €290 million for 132 new projects under the LIFE programme (2021-2027) for environment and climate action. This EU funding will mobilise a total investment of €562 million. The programme aims to help Europe become a climate-neutral continent by 2050, put Europe's biodiversity on a path to recovery by 2030, and contribute to the EU green recovery post-Covid-19. It consists of four sub-programmes, all relevant for the topic "biodiversity, climate change and energy": Nature and Biodiversity, Climate Change Mitigation and Adaptation, Clean Energy Transition, and Circular Economy and Quality of Life. Earlier LIFE programmes also covered many projects relevant to this topic, which can be searched in the LIFE public database. For instance the project (2019-25) Life Connects (EU co-funding € 5.6 million) aims at improving the conservation status of target species and ecological status of targeted rivers. Actions include removing hydropower plants and dams, and creating fauna migration passages to enable hydropower production, fish migration and riverbed restoration. Another project, FRELP (2013-16), aimed at developing innovative technologies for 100% recycling of end-of-life PV panels. It focused on developing treatments that enable the recovery of valuable raw materials from PV waste, including glass, aluminium, silicon metal, copper and silver. Some of these (e.g. silicon metal, antimony, chromium and fluorspar) are considered Critical Raw Materials for the European economy, of high economic importance with high risk of supply.

Maritime sector programmes

These are funded via the European Maritime and Fisheries Fund and projects are listed in the maritime data hub.

[5] CINEA – The European Climate Infrastructure and Environment Executive Agency. https://cinea.ec.europa.eu/our-projects_en

[6] The LIFE Programme. https://cinea.ec.europa.eu/programmes/life_en

3 Conclusions

In this report we have highlighted the importance of an integrated approach in dealing with the biodiversity, climate change and energy nexus, and described the main EU policies addressing this issue. It is crucial that actions to mitigate the urgent climate crisis do not undermine those addressing the equally urgent crisis of biodiversity loss – and that synergistic actions addressing both crises be prioritised. This includes many actions in the energy sector.

A vast amount of research and assessment studies have demonstrated the significant potential for addressing climate change and biodiversity in a mutually supportive manner, for example through nature-based solutions. Biodiversity protection and restoration play a major role in climate change mitigation by reducing net GHG emissions in a sustainable manner that preserves the integrity of ecosystems and their delivery of services essential for our health, wellbeing and very survival, including by enhancing resilience and the capacity to adapt to climate change. These studies and the relevant EU policies have been discussed in Sections 1, 2.1.1.1, 2.1.1.2 and 2.1.2.

On the other hand, there is also mounting evidence that many climate change mitigation strategies can harm biodiversity, both directly and indirectly, if potential impacts on biodiversity are not taken into account from the outset, i.e. right from the design and planning phases of climate change mitigation schemes. Assigning vast tracts of land to biofuel feedstock cultivation can accelerate biodiversity loss, as can reforestation with monocultures or non-native species, and afforestation in ecosystems that have not historically been forests. Studies relating to these concerns, and the EU policies addressing them, have been discussed in Sections 2.1.1.4 and 2.1.3.1. Renewable energy installations (such as those generating hydropower, solar or wind energy) can significantly impact biodiversity through habitat loss and fragmentation, alteration of local habitats and micro-climates, the direct impact of machinery and other infrastructure on species, and other effects that we have described in Sections 2.1.1.3 and 2.1.3.2, along with the relevant EU policies. The mining and extraction of minerals used in batteries for electric vehicles or for storage of intermittent renewable energy also pose potential challenges for biodiversity, which we have discussed in Section 2.1.3.3. Finally, the potentially significant impacts of large-scale deployment of geo-engineering options, including negative-emission technologies such as carbon capture and storage (CCS), have been discussed in Section 2.1.4, along with the EU policies addressing them.

A coherent approach is of paramount importance given these strong connections between actions to tackle the two crises of climate change and biodiversity loss and their impacts. In many cases this is already being taken into account in EU policies and initiatives, as described, while other cases are being investigated through evaluations and impact assessments. Notably, renewable energy development has to comply with EU environmental legislation (such as the Nature Directives, the Water Framework Directive, the Marine Strategy Framework Directive, etc.). Regulations on indirect land-use change, sustainability certification, LULUCF, batteries, the certification framework for carbon removals, etc. have also incorporated safeguards to prevent further biodiversity loss, while in many cases the need for enhanced safeguards has been indicated, and revisions are under development in order to ensure alignment with the EU-BDS 2030 and other environmental legislation. An important step towards an integrated approach has been taken in the establishment of a common, high-level policy framework providing strategic orientation to address both biodiversity and climate challenges, along with other EU priority objectives in relevant sectors such as energy. Under the framework of the EGD described in Section 2.1, EU policies on climate, energy and biodiversity have been considerably strengthened in recent years, with attention to ensuring coherence between their objectives and actions. Furthermore, the EGD's green oath of 'do no harm', which applies to all new EU initiatives, aims to foster coherence of EU policies with climate and environmental objectives, including biodiversity. The 8th EAP goes beyond the EGD in highlighting the importance of systemic change, prioritising biodiversity conservation as well as climate change mitigation and adaptation.

However, as illustrated in this report, incomplete understanding of the complex interdependencies between climate, energy and biodiversity policies may lead to missed opportunities for exploiting synergies and minimising conflicts. As described in Section 2.2, a large number of current and past EU Research & Innovation programmes support projects relating to biodiversity, climate change and energy, contributing to an enhanced knowledge base. The magnitude of impacts depends substantially on the technologies or schemes in question and on the environmental contexts in which the activities take place, necessitating a careful assessment from the outset. The need for integrated assessments and improved monitoring should be stressed, as well as the importance of spatial planning.

Over the coming years, due to worsening climate change and insufficient emission reductions, there is likely to be an increasing expansion of urgent climate mitigation actions, including the deployment of new technologies. In light of this urgency, an enhanced and expanded evaluation and assessment process, in line with the 'do no harm' and precautionary principles, will be crucial for avoiding unforeseen adverse impacts on nature and biodiversity.

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List of abbreviations and definitions

BDS 2030	European Union Biodiversity Strategy for 2030
BECCS	Bioenergy Carbon Capture and Storage
CBD	Convention on Biological Diversity
CCS	Carbon capture and storage
CCUS	Carbon capture, utilisation and storage
CDR	Carbon direct removal
CINEA	European Climate, Infrastructure and Environment Executive Agency
DACCS	Direct Air Carbon Capture and Storage
EAP	European Union Environment Action Programme
EGD	European Green Deal
FP7	Seventh framework programme of the European Community for research and technological development (2007-2013)
GHG	Greenhouse gas
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre
KBAs	Key Biodiversity Areas
KCBD	Knowledge Centre for Biodiversity, established by the European Commission
HE	Horizon Europe, EU funding programme for research and innovation (2021-2027)
IRENA	International Renewable Energy Agency
K4P	Knowledge for Policy, EU Commission's platform for evidence-based policymaking
LULUCF	Land use, land-use change and forestry
MS	European Union Member States
NBE	Nature-based enterprises
NBS	Nature-based solutions
NETs	Negative emission technologies
PAs	Protected areas
PV	Photovoltaics
RE	Renewable energy
RED	European Union Renewable Energy Directive
RFNBOs	Renewable fuels of non-biological origin
RTD	Directorate-General for Research and Innovation
SRM	Solar Radiation Management
UNEA	United Nations Environment Assembly
UNFCCC	United Nations Framework Convention on Climate Change
WEEE	Waste Electrical and Electronic Equipment
WFD	European Union Water Framework Directive

Nature-based solutions*: actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human wellbeing, ecosystem services and resilience and biodiversity benefits* (UNEA Resolution on Nature-Based Solutions (March 2022) for supporting sustainable development)

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