ETC CE Report 2023/7

Circular Economy and Biodiversity

Authors:
Jens Günther (UBA), Saskia Manshoven (VITO), Susanna Paleari (IRCReS), Gregory Fuchs (Ecologic Institute), Aurélien Carré (French Muséum national d'Histoire naturelle), Rikke Fischer-Bogason (PlanMiljø), Tobias Nielsen (EEA)

European Environment Agency
European Topic Centre
Circular economy and resource use

Cover design: EEA
Cover image © Joel & Jasmin Førestbird on Unsplash
Layout: ETC CE

Publication Date 9 June 2023

EEA activity Biodiversity and ecosystems, circular economy and resource use

ETC CE coordinator: Vlaamse Instelling voor Technologisch Onderzoek (VITO)

ETC CE partners: Banson Editorial and Communications Ltd, česká informační agentura životního prostředí (CENIA), Collaborating Centre on Sustainable Consumption and Production (CSCP), Istituto Di Ricerca Sulla Crescita Economica Sostenibile, Istituto Superiore per la Protezione e la Ricerca Ambiantale, IVL Swedish Environmental Research Institute, Norion, Universita Degli Studi Di Ferrara (SEEDS), Federal Environment Agency (UBA), Teknologian Tutkimuskeskus VTT oy, Wuppertal Institut für Klima, Umwelt, Energie gGmbH, World Resources Forum Association.

European Topic Centre on
Circular economy and resource use
https://www.eionet.europa.eu/etcs/etc-ce

Contents

Acknowledgements

The report has been produced within the task on 'Circular Economy and biodiversity' of the 2022 ETC/CE work program. Tobias Nielsen (EEA) has been the project leader and Jens Günther (ETC/CE) has been the task leader. The report was finalised and published under the 2023 work program of the ETC/CE.

The authors are grateful to the following experts and organisations for their comments that substantially improved the quality of the report: Tim Forslund (SITRA), Barbara Oberc and Alberto Arroyo Schnell (IUCN), Estelle Elizagoien (EU COM, DG Environment), Esther Sanye Mengual (JRC), Nikolaus Lorenz and Alexander Baic (BCG), Natacha Carvalho; Gorm Dige; Frank Wugt Larsen; Lars Mortensen; Almut Reichel; Jan-Erik Petersen; Dario Piselli; Caroline Whalley (all EEA).

The authors would also like to thank the participants of the expert workshop on 12 October 2022 for their helpful input.

Summary

The world is facing a triple planetary crisis consisting of climate change, biodiversity loss, and pollution, which pose a major challenge to human health, well-being and prosperity for present and future generations. One of the main reasons for this is our current production and consumption system. Consequently, the entire production and consumption system and the entire value chain of products and services must be considered to minimise those unsustainable levels.

Circular economy aims to transform our economy from the current mostly linear take-make-waste model towards a closed-loop model. In doing so, a circular economy can minimise the use of materials and energy, while reducing environmental pressures. It is therefore the aim of this report to analyse how circular economy can contribute to halting biodiversity loss and highlight the positive effects of circular economy measures on biodiversity in practice, following an overview of the condition of biodiversity and ecosystems in the EU together with a broad description of the main pressures to biodiversity driven by European consumption and production patterns.

The report concluded that while circular economy measures (directly and indirectly) contribute to meeting biodiversity and climate strategic objectives, the combination with biodiversity-friendly sourcing is crucial in order to halt biodiversity loss. Thus, in addition to reducing our demand for raw materials and avoiding waste and emissions, it is also necessary to introduce regenerative production processes at all stages of the product value chain. For this reason, we propose an adapted circular economy framework, which integrates regeneration as an underlying principle: the biodiversity -inclusive circular economy, with 3 core principles: (1) reduce resource use, (2) prevent waste and pollution; and (3) biodiversity-friendly sourcing. This can be linked to the R-frameworks by adding a fourth underlying boundary condition 'Regenerate' to the traditional hierarchy of 'Reduce', 'Longer use' and 'Recycle' so the bioeconomy is explicitly considered.

1 Introduction

The urgency to tackle biodiversity loss is becoming ever clearer. The IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services), in its 2019 Global Assessment Report on Biodiversity and Ecosystem Services (IPBES, 2019), found that about one million species are at risk of extinction — more than ever before in human history, and with an extinction rate about 10,000 times higher than the average historical rate. The IPBES report also shows that 75 % of the terrestrial area and about 66 % of the marine environment have been significantly altered by human actions. This results in the loss of clean air, drinkable water, pollinating insects, forests and key species, which pose as big of a threat as climate change to the survival of all terrestrial and marine species, and many experts already believe that a so-called “mass extinction event” – only the sixth in the last half-billion years – is already underway. The United Nations Environment Programme (UNEP) has stated that the world is facing a triple planetary crisis consisting of climate change, biodiversity loss, and pollution, which pose a major challenge to human health, well-being and prosperity for present and future generations (United Nations, 2020). Indeed, our well-being and prosperity is highly dependent on the preservation of biodiversity, as it provides a multitude of ecosystem services that make human life possible such as food, materials, clean water, climate regulation, cultural and spiritual enrichments, etc. In total, it is estimated that global biodiversity creates significant economic value in the form of such ecosystem services, which are worth more than $150 trillion annually—about twice the world’s GDP (Kurth et al., 2021). And an estimated 1.2 billion jobs rely on effective management and sustainability of ecosystems (ILO, 2018).

In response to this biodiversity crisis, the international community has adopted a global agreement for the conservation, sustainable use and restoration of nature at the UN Biodiversity Conference COP 15 in Montreal (Convention on Biological Diversity, 2022). By 2030, the loss of biodiversity is to be halted and the trend reversed. To achieve this, the international community has adopted four long-term targets by 2050 and 23 medium-term targets by 2030. The European Union is not only supporting those international negotiations but is trying to lead the way, under its European Green Deal, with the adoption two years ago of the EU Biodiversity Strategy for 2030 (European Commission, 2020c), which aims to put Europe's biodiversity on a path to recovery, commits to establishing a larger EU-wide network of effectively managed protected areas, and setting out a wide range of commitments and measures aimed at restoring nature, enabling the necessary transformational change.

Despite this global momentum for biodiversity conservation and restoration, our current industrialised production and consumption patterns are still causing devastating environmental impacts: about 90 % of the global biodiversity loss can be attributed to the extraction and over exploitation of natural resources (IRP, 2019). The processing, use and disposal of wastes resulting from our mode of production and consumption also have a significant impact on the condition of biodiversity, in Europe and globally. Consequently, the entire production and consumption system, as well as the entire value chain of products and services must be considered and revised, in order to minimise the pressure on biodiversity. For this reason, leading scientific organisations (Pörtner et al., 2021; IPBES, 2019) conclude that a transformative change of our consumption and production system is a central pillar to halt and reverse biodiversity loss and to tackle climate change, which is also taken up in recent international policy declarations (UNEP, 2022; Leader’s Pledge for Nature, 2020).

Such a transformation is the main goal of the Circular Economy which aims to keep materials and products in use for as long as possible, maximising their value throughout their lifecycle and recycling them at the end of it. Achieving a more circular use of materials is key to reducing the demand for virgin materials and improving resource efficiency (EEA, 2019b). In doing so, a circular economy can minimise the use of materials and energy, while reducing environmental pressures linked to resource extraction, emissions and waste (EEA, 2016). The principles of circular economy can help enable a transition towards more sustainable activities and consumptions patterns, which in turn can benefit biodiversity and nature. Nevertheless, circular economy and the intersection with biodiversity is somewhat overlooked.

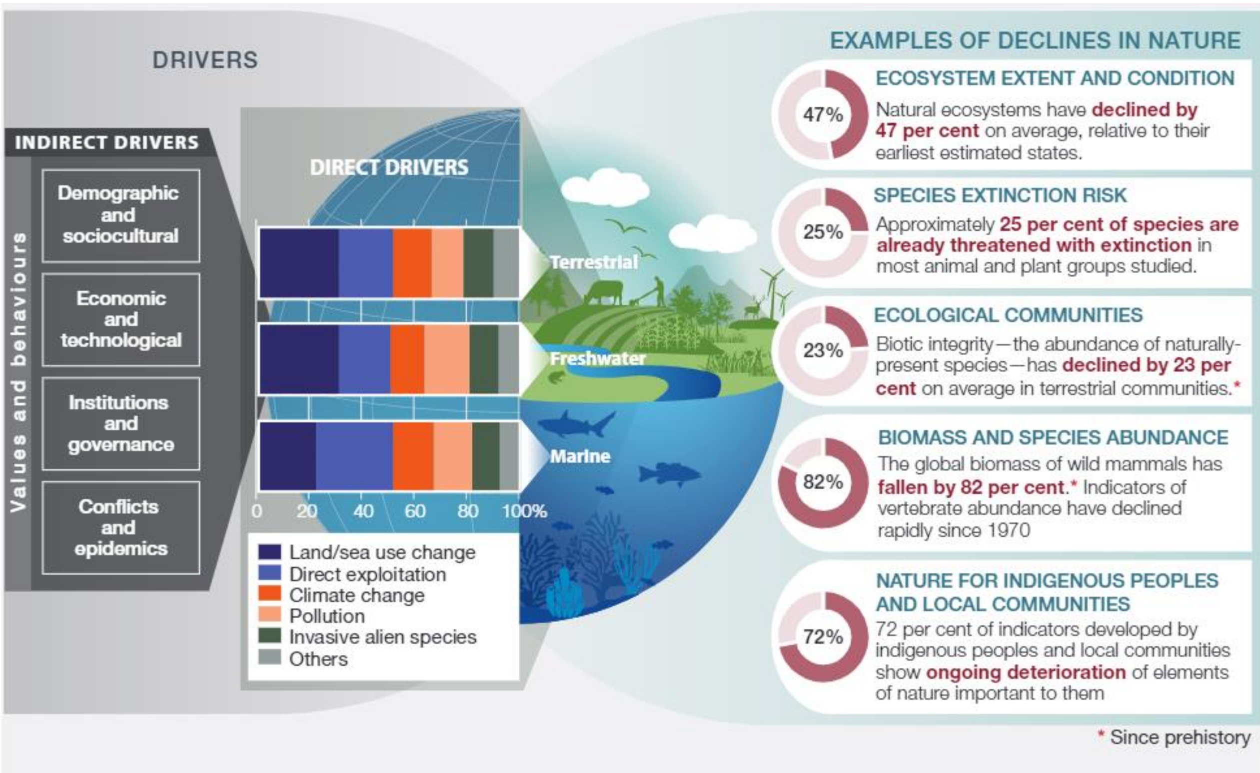
The aim of this report is to analyse how circular economy measures can contribute to reducing pressures on biodiversity, and highlight the positive effects of circular economy measures on biodiversity in practice. Starting with an analysis of the main drivers of biodiversity loss in Europe and the role of our current production-and-consumption system has in it (Chapter 2), the report shows how changing our production-consumption system through an ambitious implementation of the Circular Economy can contribute significantly to halting biodiversity loss (chapter 3). Concrete projects and approaches in relevant value chains are then used to illustrate the exemplary implementation of the conceptual framework developed (chapter 4). The report concludes with guidance on aspects that should be considered when designing circular economy policies in order to minimise pressures on biodiversity and enable its restoration and shortly describes the role of policy, business and consumers.

2 Pressures on biodiversity and ecosystems driven by European consumption and production

Biodiversity is traditionally defined as the variety of life on Earth, in all its forms. It comprises the number of species, their genetic variation and the interaction of these lifeforms and their physical environment within ecological complex called ecosystems. Maintaining the integrity of biodiversity in all its components is the condition for guaranteeing human well-being, as it is indisputably dependent on ecological systems and the benefits they provide to people.

Climate change has rightly attracted attention as a recent and accelerating driver of biodiversity loss, but it is not (yet) the most intense, and other drivers are still causing widespread biodiversity loss. Five key direct drivers of biodiversity loss have been identified worldwide by the IPBES experts: Changes in land and sea use; Direct exploitation of natural resources; Climate change; Pollution; and Invasion of alien species (Figure 2.1). In the figure, the colour bands represent the relative global impact of direct drivers, from top to bottom, on terrestrial, freshwater and marine nature. Land- and sea-use change and direct exploitation account for more than 50 % of the global impact on land, freshwater and sea, but each driver is dominant in certain contexts. The circles illustrate the magnitude of the negative human impacts on a diverse selection of aspects of nature over a range of different time scales.

Figure 2.1 Examples of global declines in nature emphasising declines in biodiversity that have been and are being caused by direct drivers of biodiversity loss, themselves under the influence of indirect drivers



Source(s): (IPBES, 2019)

In the context of IPBES, drivers of change are *"all the factors that, directly or indirectly, cause changes in nature, anthropogenic assets, nature's contributions to people and a good quality of life"*.

- "Direct drivers" of biodiversity loss (Land/sea use change, Direct exploitation, Climate change, Pollution, Invasive alien species, others) have direct physical (mechanical, chemical, noise, light etc.) and psychological (disturbance, etc.) impacts on nature and ecosystem functioning. Direct drivers, also referred as 'pressures', unequivocally influence biodiversity and ecosystem processes, but they are resulting from an array of underlying societal causes;

- Those societal causes called "indirect drivers" of biodiversity loss can be demographic (e.g., human population dynamics), sociocultural (e.g., consumption patterns), economic (e.g., trade), technological, or related to institutions, governance, conflicts and epidemics, and all underpinned by societal values and behaviours (IPBES, 2019).

The distinction between "indirect" and "direct" drivers was popularised by the Millennium Ecosystem Assessment (MEA, 2005) and this classification still dominates the debate on ecosystem change (e.g. Pereira et al., 2010). The **DPSIR** terminology (drivers, pressures, states, impacts, responses), developed in Europe by the EEA (EEA, 1999), divided drivers into "driving forces" and "pressures", respectively corresponding to indirect drivers and direct drivers (Tzanopoulos et al., 2013). "Impacts" therefore refer to the quantitative changes in the condition of the environment resulting from the pressures, themselves guided by driving forces. The intensity of those changes determines the quality of ecosystems, and the welfare of human beings (IPBES, 2018).

As such, understanding and assessing anthropogenic impacts on nature are of growing scientific, political, and societal concern. And knowing which of the human activities are influencing biodiversity (driving forces), which human pressures are direct drivers of biodiversity loss and ecosystem disruption, and to which extent, is necessary for designing new systemic policies and actions that can achieve major sustainability objectives, such as the post-2020 global biodiversity framework of the CBD, the Sustainable Development Goals (SDGs) of the United Nations or, in the EU, the objective of the EU Green Deal and the Biodiversity Strategy for 2030. And all policies that wouldn't mitigate the direct drivers of biodiversity loss resulting from our activities will never have overall positive effects, regardless of their impacts on indirect drivers earlier in the causal chain, or in terms of changes in practices (Jaureguiberry, Pedro et al., 2022).

2.1 Drivers of biodiversity loss in Europe

In Europe, according to the IPBES regional biodiversity assessment (IPBES, 2018), it is also the land-use change that is the major direct driver of the loss of both biodiversity and ecosystem services, in relation to the intensification of agriculture and forestry together with urban development. The following drivers of biodiversity loss in Europe are climate change, resource extraction, invasive alien species, and pollution. The experts reminded that European natural ecosystems have declined both in extent (e.g., wetland extent has declined by 50 % since 1970) and in terms of species diversity (28 % of species living exclusively in Europe and Central Asia are threatened), while landscapes and seascapes have become more uniform in their species composition, and thus, their diversity has declined. One conclusion of this report is that the economic growth is causing this decline in biodiversity, because it is generally not decoupled from environmental degradation. This necessary decoupling would require a transformation in policies and tax reforms across the whole region.

The recently published EU Ecosystem assessment (Maes et al., 2020) included as a main objective to analyse the changes in pressures on ecosystems and ecosystem condition relative to the baseline year set for 2010, for the main European Ecosystem types: Urban, Agroecosystems, Forests, Heathlands and Shrubs, Sparsely vegetated lands, Wetlands, Rivers and Lakes, and four Marine regions. The report identified similar direct drivers of biodiversity loss in Europe as the IPBES (**Error! Reference source not found.**). The detailed analysis c oncluded that the negative effects of climate change were on the rise over the past decade in the EU, while the intensity of the other human-induced pressures to ecosystems, like habitat conversion or pollution, have not really changed in intensity, yet continuing to slowly degrade biodiversity and ecosystem condition. Another assessment initiative that was implemented for the first time in 2016 was the European Red list of habitats, which provided an overview on the character, extent and status of 233 natural and semi-natural terrestrial and freshwater habitat types. Those assessments gave a clearer picture of the extent of the degradation of biodiversity over the past decades, revealing that the most widespread and severe dangers to European terrestrial and freshwater habitats are related to the various kinds of agricultural activities that are taking place in the EU (European Commission, 2016). These agricultural activities include both intensification for more productive farming, but also the abandonment and substitution of traditional land-use practices, which especially affect grassland ecosystems. In addition, direct and indirect effects of hydrological change in river flows, together with eutrophication from agriculture and farming, have severely affected freshwater habitats. Coastal habitats are on their side particularly threatened by the increasing coastal urbanisation, and the development of its associated infrastructures and communications systems, while the most frequently cited pressures for marine ecosystems, were pollution (eutrophication), the over-use of biological resource (mainly fishing, but also aquaculture), the modification of natural systems (e.g. dredging and sea defence works), urbanisation and climate change. The overall impacts of climate change on the EU's biodiversity were, however, hard to assess in detail, despite the fact that some changes are clearly measured and are surely increasing.

Figure 2.2: Long-term trends of pressures in terrestrial and freshwater ecosystems based on a selection of policy relevant indicators

Pressure class	Indicator	Urban ecosystems	Agroecosystems	Forest	Wetlands	Heathland and shrub	Sparsely vegetated land	Rivers and lakes
Habitat conversion and degradation	Land take	?	↑	↑	→	↑	↑	→
	Intensification / extensification		?					
	Change in forest extent			→				
Climate change	Mean temperature		↓	↓				?
	Extreme drought events		↓	↓	↓			
	Effective rainfall		↓	↓				
Pollution and nutrient enrichment	Emissions of NO2, PM10, PM2.5	↑						
	Formation of tropospheric ozone (ground level ozone)			↑				
	Gross nitrogen balance		→					→
	Critical load exceedance of nitrogen*		↑	↑	↑	↑		↑
	Gross phosphorus balance		↑					↑
Over-harvesting in forests	Long term ratio of annual fellings to net annual increment			→				
Invasive alien species	Number of annual introductions of invasive alien species	?	?	?	?	?	?	?

↑ improvement; → no changes, ↓ degradation; ? unresolved (see also Chapter 2 for definitions); This table is based on the summary tables presented in Chapter 3. Cropland and grassland are considered together in agroecosystems; * for rivers and lakes the matching indicator is Atmospheric nitrogen deposition

Source(s): (Maes et al., 2020)

The last published 'State of Nature' report (EEA, 2020d) describing the state of species and habitat types protected under the Natures Directives over the period 2013 to 2018, showed that only 15 % of the overall habitat assessments have a good conservation status, while 81 % have poor or bad conservation status. In terms of habitat types, the two most damaged habitat groups appear to be 'Dune' and 'bog, mire and fen', of which more than 50 % of their related habitat types have a bad conservation status at EU level. For the 2012-2018 reporting period, Member States reported over 67,000 records from one of the 203 individual pressures for species (including birds) and habitats. Around one third of these reported pressures are considered to be of 'high importance', with slightly more pressure records of high importance for non-bird species (35 %) than for habitats and birds (around 32 %).

Thanks to those diverse assessments of ecosystems, habitats and species, and to the mandatory reporting of the main pressures and threats to the biodiversity protected under the Nature Directives, as well as to a few other specific references, the following major drivers of biodiversity loss occurring within the EU can be identified and described.

Unsustainable management practices and ecosystem uses, including land-take and species exploitation

Today's dominant agricultural practices are by far the most important source of pressures affecting terrestrial habitats and species in Europe. Agriculture is indeed the most common overall 'pressure' reported in the EU for terrestrial biodiversity under the Habitat Directive, and in particular the intensification of management practices, especially affecting 'Grasslands', 'Freshwater habitats', 'Heath and scrub' and 'Bogs, mires and fens' habitat groups, as well as reptiles, molluscs, amphibians, arthropods, vascular plants and breeding birds. Agriculture is also the main sector contributing to air, water and soil pollution, accounting for about 48 % of all pollution-related pressures reported under the Nature Directives, with significant impacts on standing waters, rivers and marine habitats and their species (EEA, 2020d). However, extensive agricultural management can create and maintain semi-natural habitats with a diverse fauna and flora. Yet, those extensive and traditional practices are being progressively abandoned, in relation to the intensification and the specialisation of the agricultural sector since the 1950's which has increasingly contributed to the ongoing biodiversity loss. Many studies have indeed documented that biodiversity richness and species abundance in agro-ecosystems negatively correlate with the degree of modification (e.g., drainage, ploughing) and intensification of agricultural management (e.g., use of fertilizers, irrigation, and pesticides) (Altieri, 1999). As a result, 'Changes in agricultural management' is now the most frequently reported sub-type of pressure related to agriculture at the EU level.

Urbanisation, or soil artificialisation, is the second largest pressure and threat reported on protected habitats and species in Europe by the EU Member-States. Land take for urban and other artificial land development, which include urban development and land use for residential, commercial, industrial and recreational purposes, as well as dispersed recreational and leisure activities, especially affects coastal habitats that have a restricted distribution, such as dunes and rocky habitats (EEA, 2020d). The EU Ecosystem assessment however highlighted that, since 2010, land take is decreasing in all ecosystems, except in wetlands, floodplains and riparian areas along rivers and lakes. Still, the assessment of urban ecosystems also shows that soil imperviousness is significantly increasing in urban areas, where land is generally inefficiently used and driven by urban sprawl rather than densification.

Today's dominant forest management practices and forestry activities are on their side corresponding to the third largest source of pressures for protected habitats and species under the Nature Directives, and are also among the main reported pressure on European species, especially for arthropods, mammals and non-vascular plants. Those pressures are mainly driven by the increased extraction of forest products and the intensification of forestry practices. In addition, the increasing use of forests as a source of renewable energy poses one of the major forest-related policy challenges.

Water abstractions pose heavy pressure on freshwater ecosystems, especially where water availability is limited. It is estimated that about 350,000 million m^3 of water are extracted annually in the European region for human activities, which represent approximately 10 % of Europe's total freshwater resource. Still, because about 88 % of Europe's freshwater use (drinking and other uses) comes from rivers and groundwater, and because water demand across Europe has steadily increased over the past 50 years, only partly due to population growth, the renewable water resources per capita decreased by 24 % across Europe since the 1970's.
In a number of places where water is being pumped from beneath the ground faster than it is being replenished through rainfall, the result is the sinking of water tables, which are crucial for sustaining functional level of water in lakes and wetlands, often highly productive ecosystems and resources for tourism, as well as leisure activities. The sinking of water tables is also increasingly reducing the availability of water for plant species, which is becoming the limiting factor of the good condition of many ecosystems.

Sinking of water tables can also make rivers less reliable for water supply, since many river flows are maintained in the dry season by springs that dry up when water tables fall. When happening in in coastal areas, groundwater abstraction often results in the intrusion of saltwater from the sea, which especially occurring along the Mediterranean coastlines of Italy or Spain where the demands of tourist resorts are the major cause of over-abstraction (EEA, 2020c).

Still, agriculture is responsible of most of water abstractions: while only around 9 % of Europe's total farmland is irrigated, those areas still account for about 50 % of total water use in Europe. For example, in the spring of 2014 agriculture used 66 % of the total water consumed in Europe, and around 80 % of total water abstraction for agriculture occurred in the Mediterranean region. At the same time, around 40 % of the inhabitants of this region lived under water stress conditions (EEA, 2019c). Yet, household uses are only accounting for around 12 % of yearly water extraction in the EU, behind energy production (28 %), and mining and manufacturing (18 %). Despite the improvements observed since 2000 (-7 % for 2000-2015), the reduction in water abstractions did not significantly changed since 2010 and may not continue in the foreseeable horizon (Maes et al., 2020).

The **exploitation of species** is the sixth largest category of reported pressures for habitats and species under the Nature Directives, and it is the most significant overall pressure group for wintering and passage birds. Non-bird species are also affected, especially mammals, reptiles and fish species. Illegal shooting or killing, as well as marine and freshwater fisheries activities, are the most important pressure reported, before hunting and bycatch. Trends available for marine fisheries are showing that catches of commercially exploited fish and shellfish exceeding fishing mortality at maximum sustainable yield (F_{msy}) is still increasing in the Mediterranean Sea and the Black Sea, now reaching more than the double of this sustainable yield. The situation is, however, improving in the Baltic Sea and in the North-east Atlantic Ocean.

The unsustainable natural resource use and management practices described above are directly linked to our current production and consumption system, but are influenced by it more strongly and over shorter timescales for some than for others. Forestry and agriculture, for example, are arguably more directly influenced by (changing) consumption and production patterns than, for example, urbanisation. Urbanisation also responds to consumption and production (e.g., through industrialisation, commercialisation), but more indirectly, as it is also influenced by other factors (e.g., social benefits of urban areas causing migration to cities, demographic change). Pollution, chemical contamination, and nutrient enrichment are linked to these practices, but also occur in other contexts, constituting an additional range of pressures on terrestrial habitats and species in Europe.

Pollution, chemical contamination and nutrient enrichment

Marine litter is one of the most visible types of pollution caused by human activities and have huge impacts on ecosystems (Guitart et al., 2019). Yet, trends in pressure from litter are still difficult to assess reliably, especially for seafloor litter and microplastic litter. In response, the scientific community proposed a threshold level for microplastics above which significant ecological risks occur in marine waters (concentrations of 1.21 x 105 items per m^3), and this threshold has already been exceeded in certain pollution hotspots, including the Mediterranean Sea. The recent report commissioned by the WWF on impacts of plastic pollution in the oceans and marine species (Tekman et al., 2022) reminds that the majority of marine plastic pollution comes from land-based sources, near coastlines and rivers further inland.

In Europe, a recent analysis estimated a release of 307 to 925 million litter items into the ocean annually, of which 82 % are plastic (González-Fernández et al., 2021). Another study estimated that at least 22 % of marine litter comes from fisheries. The wear of vehicle tyres and brakes are a less-known but major source of microplastic emissions through runoffs, while the air is a vector for plastic pollutions in relation with the wind abrasion from plastic-coated surfaces, waste processing, roads and agriculture. To shed further light on the issues, the European Commission (DG Environment) has launched an impact study on unintentional release of microplastics which includes the following key sources: paints, tyres, pellets, textiles, geotextiles, and detergent capsules (European Commission, 2022c).

Regarding freshwater ecosystems in Europe, only 38 % of monitored lakes, rivers and other surface water bodies are in good chemical status, meaning where the concentrations of pollutants are not exceeding environmental quality EU-wide standards. In most Member States, only a few substances are accounting for poor chemical status, the most common being Mercury, once widely used in thermometers, batteries, and paints but continuing to be found in water samples from coal burning, followed by Cadmium, which is present in phosphate fertilizers and rejected from metal production (EEA, 2018a). However, the concentration of nutrients and the associated biological oxygen demand within rivers and lakes (but not and in ground water) has steadily decreased since 1992[1] in relation to improvements in waste water treatment (EU Nitrates Directive and national measures). Still, this apparent stabilisation in recent years may call for further measures to be taken, while the bathing water quality in both freshwater and marine ecosystems is improving. Pressures caused by emissions of pollutants to the atmosphere or to surface waters (nutrients nitrogen and phosphorus) are also declining (Maes et al., 2020)), like tropospheric ozone in forests (a secondary pollutant caused by nitrogen emissions), while the gross phosphorus balance is improving in agroecosystems. However, pesticide sales remained stable since 2010 at around 380 thousand tonnes per year at EU-level, so that concentrations in the environment are likely to remain unchanged or increasing with respect to the baseline year 2010, because of accumulation.

In summary, pollution of air, water and soil from different origins still negatively affects most protected habitats and species, and agricultural activities as clearly a key source of pollution (air, water and soil). Atmospheric emissions and air pollution also have a significant impact in terrestrial habitats especially reactive to nitrogen deposition, which in 2020 exceeded the critical load for eutrophication of water in approximately 75 % of the total EU-27 ecosystem area (EEA, 2022g).

A recent study concluded that humanity is currently operating outside the ‘novel entities’ planetary boundary, because the increasing rate of production and releases of larger volumes and higher numbers of those novel entities (novel in a geological sense, and of entities that could have large-scale impacts that threaten the integrity of Earth system processes) exceed our ability to conduct safe and robust assessments and monitoring of their impacts (Persson et al., 2022). Plastic pollution is a particular aspect of high concern, but not the only one. The authors also underline that the persistence of many novel entities and/or their associated effects, and especially the effects resulting from the mixture of these entities, will continue to pose a threat in the long-term future.

Climate change

Climate change has not been reported as a particularly relevant pressure by EU Member States for habitats and species in the last decade (ninth rank of pressures reported under Nature’s Directives). Nevertheless, Climate change is already happening and has noticeable impacts, such as rising temperatures (in air, sea and freshwater), more frequent periods of drought and wildfires, shifting rainfall patterns, melting glaciers, less snow and a rising global mean sea level (European Commission, 2016). The five warmest years on record for Europe have all occurred since 2014 (Copernicus, 2022). Moreover, Climate change is becoming increasingly important and a growing threat, as evidenced by research on future scenarios predicting dramatic impacts on European plants and animals in the coming years, and as shown in the EU Ecosystem assessment (Maes et al., 2020). It is already more pronounced in an area spanning from Portugal to Romania, including south France, the entire Mediterranean, and the Danube River basin, which are especially affected by an increasing number of wildfires. The droughts in 2017, 2021 and 2022 led to some of the worst wildfire seasons in Europe in recent decades - both years saw more than a million hectares burnt by wildfires (San-Miguel-Ayan et al.,

[1] Following EEA (2022e) the Biochemical oxygen demand (BOD) in the European rivers fell to half of the 1992 level, but remained steady at around 2.5 mg O2/l since 2011.

2022). The northern regions of Sweden and Finland are also experiencing increased climate impacts in comparison with areas in Western Europe, as well as the European plains between Brittany in France and Southern Finland.

Globally, the decrease in effective rainfall combined with the increase of extreme drought events in forests and agroecosystems are of specific concern, as water is the limiting factor for forests and agroecosystems and is essential for delivering ecosystem services such as food, timber, or carbon sequestration. As for marine ecosystems, sea surface temperature and sea level are significantly increasing, and marine ecosystems are acidifying continuously.

Invasive alien species (IAS)

Invasive alien species (IASs) are animals and plants that are introduced accidentally or deliberately into a natural environment where they are not normally found, causing serious negative effects in their new environment. IUCN, the World Conservation Union, stated that the impacts of IASs are immense, insidious, and usually irreversible, and may be as damaging to native species and ecosystems on a global scale as the loss and degradation of habitats (IUCN, 2018). Indeed, those alien species that thrive after appearing in new environments become invasive when native species are not prepared to defend themselves against the invaders. This process has been a major cause of extinction of native species throughout the world, over the past few hundred years and even more over the past decades, while the growing global trade and communication directly contribute to the mixing of wildlife across biogeographical boundaries.

The EU has defined a list of 49 Invasive alien species (IASs) of union concern, like *Acacia saligna* (Golden wreath wattle), *Ailanthus altissima* (Tree of heaven) or *Sciurus carolinensis* (Grey squirrel) which pose the highest risks for terrestrial and freshwater ecosystems and biodiversity, although marine ecosystems are not fully considered (EU, 2014). Currently, there are no EU-wide trends for these IASs, but the baseline data for 2010 used for the EU Ecosystem assessment shows that urban areas and grasslands are particularly affected by IAS of union concern, with an estimated pressure on over 60 % of their total extent. IASs of union concern account for 'only' 20 % of pressure reported for IAS under the Nature Directive, the seventh largest category of pressures reported for habitats and species. Much greater impacts were reported from other IASs, and the impact of IASs increased in importance for both habitats and species compared with the last reporting period (2007-2012). IASs affect habitats more than species, but they do affect especially amphibians, fish, vascular plants and breeding seabirds.

2.2 Consequences of biodiversity loss on ecosystem functioning and services

The IPBES particularly identifies the growth of population and the global economy and trade, which accelerate the need for energy, materials, and food supply, as the indirect drivers to global change and the biodiversity crisis. The main pressure on the environment resulting from those indirect drivers is certainly the global expansion of agriculture, which in turn contributes to pollution of water and land, and increase in land-use and climate change: over one-third of the global terrestrial land surface is used for crop and animal farming. Unsustainable consumption and production patterns amplify impacts on biodiversity. For example, commercial agriculture, as opposed to organic agriculture is associated with higher biodiversity impacts. These include amongst others greater soil degradation and species loss caused by higher levels of pollution and nutrient loading, destruction of natural landscape features and soil compaction resulting in a less viable environment. Moreover, sustainability of activities is critical to biodiversity impacts at each stage of the value chain, where, for example, energy use and waste generation associated with production, transportation, and retail can vary widely. One of the factors influencing this is the level of circularity of those value chain activities.

Moreover, while the main drivers of biodiversity loss are damaging the biological diversity of our planet, the resulting biodiversity changes can in turn have impacts on ecosystem processes, leading to further biodiversity loss. In addition, changes in ecosystem ecological processes are strongly affecting the provision of ecosystem services and goods, which directly affect human benefits from nature. It is not possible to estimate the full value of biodiversity and ecosystems, but it is still important to highlight the services and goods that ecosystems can deliver to human society, and by that to understand and try to quantify the cost of the failure to protect biodiversity and ecosystems. The term ‘ecosystem services’ was introduced for this purpose, as to describe the providing, supporting and improving services, like the cleaning, recycling, and renewal of the natural environment.

Disruption of ecosystem ecological processes

The **overall modification of hydrological regimes** was reported as one of the most important overarching pressures on protected habitats and species in the EU. Those modifications are linked to any intervention on hydrological regimes of waterbodies, like the regulation or damming of the watercourse, as well as any morphological deterioration and physical changes in waterbodies by anthropogenic activities like dredging, artificial material, channelisation, embankment, etc., which may have adverse impacts on the environment via the deterioration of aquatic habitats, which cause loss and change of biological species and composition (EEA, 2020d). Agricultural activities, urban development, navigation, flood protection and defence, mineral extraction, energy production or recreational use, are the main activities responsible for modification of hydromorphological properties of waterbodies in Europe, through water storage, water transfer, channelisation, or the deforestation of riparian buffer zones. Those modifications directly affect the physical habitat of aquatic life, but may also affect the functioning of terrestrial habitats in interaction with waterbodies, like wetlands, ecosystems showing the worst condition in Europe.

The resilience capacity of European ecosystems, and especially forest ecosystems, is also heavily affected by human activities. Indeed, EU-wide indicators are showing that forest fragmentation, abundance of forest birds and area of protected forest are stagnating, and also that there is no improvement of the conservation status of forest habitats that have an unfavourable conservation status. Most importantly, defoliation, a key natural bio-indicator that can be used as an early warning system to monitor forest’s health, is showing a significant negative trend, with an estimated rate of change between 3.4 and 16.5 % since 2010. This illustrates the potential issue of European forest to be able to adapt to climate change, while already facing pressures from forestry, pollution and land take. The only forest structural indicators that are exhibiting an upward trend are dead wood, forest area and wood biomass. But the increase in deadwood can be linked with the increasing frequency of intense weather events due to climate change, while forest area and biomass are mostly increasing because of land abandonment and forest recolonisation of former agricultural lands.

The ecological balance in agroecosystems, in the sense of all anthropogenic ecosystems subjected by human to continuous modifications of their biotic and abiotic components for the production of food and fibre, also show a continuous decline. This is reflected by the strong decline of farmland birds and grassland butterflies, the most critical and an alarming signal of this degradation. Farmland birds are indeed declining with almost 14 % per decade, while the average decline of grassland butterflies in the EU is as about 22 % per decade; The fact that birds and butterflies species that were able to survive in agroecosystems over the past decades are currently strongly declining in Europe, while the intensification of agricultural practices mostly occurred prior to this decline, clearly means that we are facing an unbalanced situation. In addition, fallow lands, which are important refuges for agricultural biodiversity, have known a rapidly and drastic decline of about 60 % since 2010, caused by the abolishment of the CAP set aside requirements in 2009. The condition of fallow land has also been strongly affected in 2022, as the European Commission granted a temporary derogation for growing crops on set-aside lands. Four million hectares are concerned, with the biggest impact in France, Germany, Italy and Spain, which together account for about 70 % of the set-aside land designated as an Ecological Focus Area.

Soil health and integrity is also under high pressure from a wide range of drivers, including agriculture, mining and urbanisation, reflecting the strong competition for land. Urban expansion leads to soil sealing and loss of function, intensive agriculture to soil compaction, loss of organic matter and biodiversity, contamination from fertilizers and pesticides and increased soil erosion, while industrial activities lead to soil sealing and industrial pollution from local and diffuse sources. As a result, it appears now that mineral cropland soils show the lowest soil carbon stocks of all land cover types in Europe, apart from artificial areas, and may already have reached a critical threshold. In addition, soil erosion rates across the EU is still equivalent to 2.45 tonnes per ha per year, above the accepted soil formation rates between 1.4 and 2 tonnes per ha per year. This means that the soil ecosystem will continue to degrade in the future. Regions with high levels of erosion, like the Mediterranean region, show limited improvements, reflecting a combination of limited soil cover, limited implementation of control measures, increasingly erosive rainfall patterns and terrain conditions. More generally, and despite some improvements based on the growing share of organic farming, the overall structural condition of agroecosystems is continuously deteriorating.

Degradation of ecosystem services provision

The EU Ecosystem assessment published in 2020 (Maes et al., 2020) also provided an assessment for six ecosystem services (Box 1) between 2000 and 2012: crop provision, timber provision, carbon sequestration, crop pollination, flood control and nature-based recreation. Based on information about the potential for provision, use and demand of ecosystem services, the report shows that the potential quantity and quality of services that the EU ecosystems collectively deliver varies from being stable to further eroding, for all the six ecosystem services studied (50 % stable and 50 % decreasing). In contrast, there is a growing demand from people for ecosystem services, from timber sources to carbon sequestration and recreation. The assessment of the unmet demand has also shown that there is a large gap between the societal needs for ecosystem services and the amount of services effectively delivered by ecosystems.

Box 1: Ecosystem Services

Ecosystem services (ES) are defined by the Common International Classification of Ecosystem Services (CICES) as the contributions that ecosystems make to human well-being and our economies, but distinct from the goods and benefits that people subsequently derive from them. They are of 3 types: (i) Provisioning services, when ecosystems provide products such as food, fibre or timber, (ii) Regulating and maintenance services, when ecosystem can buffer environmental pressures or reduce the impact of natural hazard and contributing to safety of society, like carbon sequestration, water purification or flood control and (iii) Non-material or Cultural benefits to people, such as spiritual enrichment and recreation.

The pace of this change is still relatively low, as it is influenced by large-scale changes in land cover and land use, ecosystem condition as well as other environmental variables that define the potential of ecosystems to deliver services. Still, both ecosystem extent and condition determine the potential of ecosystems to provide services. And when this potential is used, ecosystem services flow from ecosystems to humans and deliver benefits. But when the demand for ecosystem services increases, it frequently happens at the expenses of a decrease in the ecosystem service potential. This may lead to a situation in which ecosystems cannot continue to satisfy the need for the services, declining the contribution of ecosystems to human well-being.

EU Ecological footprint: showing environmental pressures outside the EU's territory

The ecological footprint is an area-based measure to assess the ecological assets that a given population or product requires to produce the natural resources it consumes. The Living Planet Report, published by the WWF, estimates that humanity's global ecological footprint (on the entire biosphere) is mainly distributed among food (30 %), housing (22 %), and personal transport reported separately at 15 % of the estimated footprint (WWF, 2022b). When applied to the EU, it is a very efficient method to highlight the overall pressure of the EU consumption on biodiversity worldwide, and not only the biodiversity condition within the EU territory. And the numbers are speaking: Western and Central Europe's ecological footprint is more than twice the size of the biocapacity available (EEA, 2020b). Depending on the type of pressure, between 24 % and 56 % of the associated total EU footprint occurs outside Europe. For example, of the land footprint associated with products consumed within the EU, on average 56 % is estimated to lie outside the

EU territory. Deforestation and over-fishing are two spoken examples for documenting the impact of EU consumption outside of its territory.
A recent WWF report reminded that EU consumption has driven the loss of millions of hectares of forests and other natural ecosystems, fuelling climate change, biodiversity loss and social injustices (WWF, 2022a). The EU remains today the second-largest importer of products linked to tropical deforestation after China. In economic terms the EU is the world's largest exporter of agri-food products, but in fact, when counting protein and calories, the EU has a significant trade deficit because our food production is largely dependent on high imports of agricultural inputs, such as animal feed or fertilisers (WWF, 2022a). Soy is indeed the imported agricultural commodity that drives the most deforestation of tropical forests: it was responsible for 31 % of the tropical deforestation embedded in EU imports between 2005 and 2017, an average of 89,000 hectares per year.

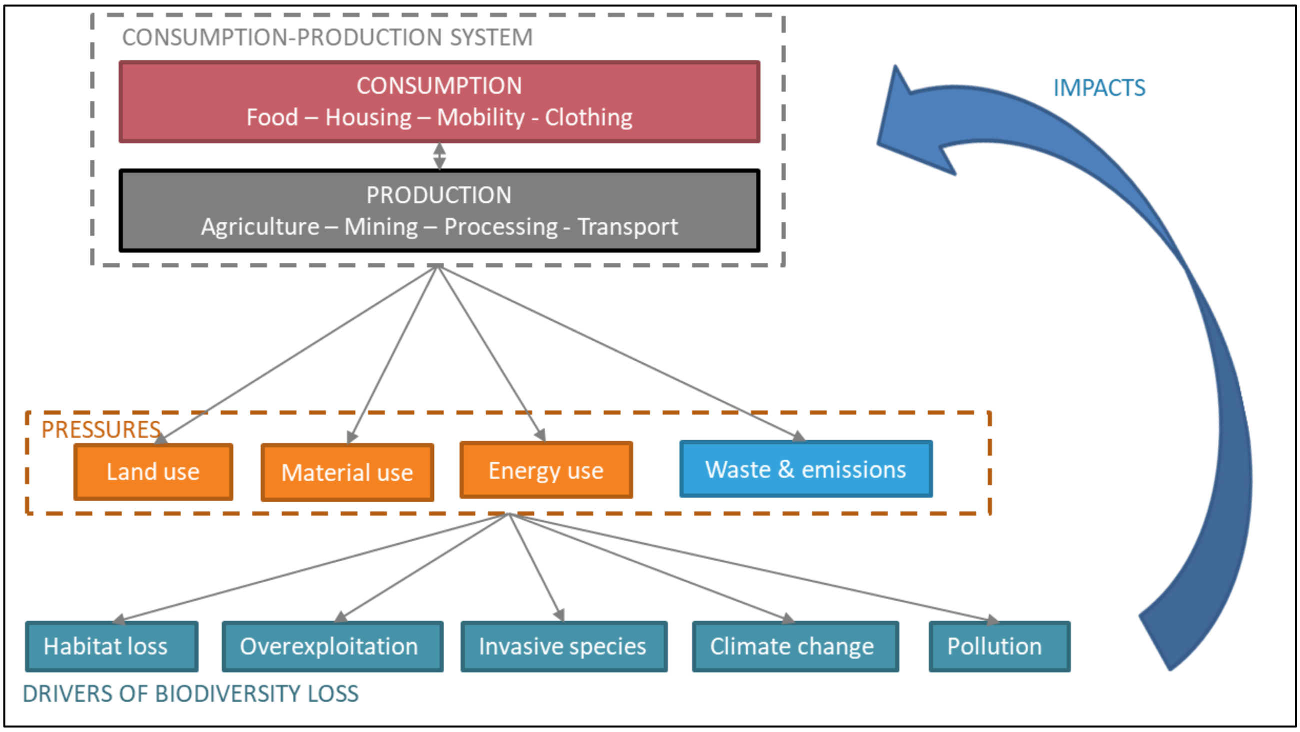
The EU is also the world's largest seafood importer, importing more than half of what it consumes. The average person living in the EU consumes about 24 kg (live weight) of fish or seafood per year, representing 3.3 kg more than in the rest of the world. And by adding seafood processed for feed production, seafood consumption in EU member states is reaching 27 kg per head. The supply of fisheries and seafood products to the EU market is partly ensured by the EU's own production (about 5 million tonnes) and by imports (9.5 million tonnes), leading to an 'apparent consumption' of 12.3 million tonnes when subtracting exports.
While domestic fishing and aquaculture represent only a third of the EU consumption of fish and seafood, it is estimated that nearly 38 % of fish in the North East Atlantic and Baltic Sea, and 87 % in the Mediterranean and Black Sea, are being overfished. The number of overfished stocks globally has tripled in half a century, and today fully one-third of the world's assessed fisheries are currently pushed beyond their biological limits, according to the Food and Agriculture Organisation of the United Nations. Fishing is now one of the most significant drivers of declines in ocean wildlife populations. The JRC has developed in 2018 a "Global seafood consumption footprint" (Guillen et al., 2019). This indicator revealed that 41 % of the global capture fisheries production enters international trade, 27.5 % of the production from the seafood distribution and processing industries and 68.6 % of the fishmeal and fish oil production. These results confirm the importance of international trade in seafood products, and particularly the trade in fishmeal and oil, as well as the relatively high trade in production from capture fisheries compared to aquaculture. Indeed, only 17.6 % of global aquaculture production is internationally trade, but fishmeal and oil and mostly used in aquaculture: aquaculture rely on international trades of fishmeal and oil to supply for local consumption. Yet, aquaculture only accounts for about 20 % of fish and shellfish supply in the EU, of which more than 45 % is shellfish production which do not depend on fishmeal and oil.

Those are only few but speaking examples of how the EU production and consumption, by its direct influence on the globalised and industrialised production system, affects not only species, habitats and ecosystem functioning within the EU's territory, but are also key drivers of pollution and destruction of some of the most important ecosystems on our planet, like oceans and tropical forests. Indeed, the described assessments and data show the clear picture that biodiversity is increasingly degrading in Europe, as it is globally. It also highlights how our current consumption and production system is at the very root of this problem.

2.3 How current production and consumption patterns impact biodiversity

When looking more specifically at the production side, and questioning which stage of the industrialised production processes show the strongest impacts on biodiversity, it appears that 'raw material extraction' and 'cultivation' represent roughly 60 % of the pressure on biodiversity that can be accounted to the primary-production sector. Another 20 % can be allocated to the conversion of raw material, the processing and manufacturing processes in industrial production systems, the overall energy generated for the sector and the need for infrastructure construction. The remaining 20 % of pressure on biodiversity are accounted for different services like mobility, traveling or health care, as well as to unsustainable consumption habits, especially inefficient use of goods and improper handling of waste (Kurth et al., 2021, p. 16f.). Therefore, the relations between biodiversity loss and the production system are diverse and complex.

Figure 2-3 How consumption and production relate to the main drivers of biodiversity loss



Source: ETC/CE and EEA

When the dominant production and consumption system is taken as a whole, and in relation to the scale of the 'direct drivers' of biodiversity loss (pressures) identified by the IPBES, the main pressures related to this system can be bundled into the following categories (Figure 2-3, exemplary, non-exhaustive):

- **Land use, land-cover and land-management changes**: Our need for space, whether it is to produce food, to live, to recreate, to work or to provide energy and materials, affect the way we use land and have either altered land surface properties (land cover changes), or modified characteristics of the existing land cover (land management changes). In most cases, land used for anthropogenic purposes and land cover changes, like deforestation for cropland expansion, urban growth over arable lands and grasslands, open-cast mining or polder drainage of coastal wetlands, induce ecosystem modification, habitat fragmentation and habitat loss, and have harmful effects on biodiversity. Human land-use activities have also resulted in large changes to the biogeochemical and bio-geophysical properties on Earth, with profound implications for the climate system (albedo, evapotranspiration, and roughness). It is estimated that about 40 % of the present-day radiative forcing involved in climate change can be attributed to land-cover changes since the Industrial revolution and its effect on the Earth's albedo, the rest being mostly linked to changes in atmospheric gas.
- **Material use**: The way we use land to produce raw materials and goods, and the intensity with which they are produced, is also leading to the overexploitation of some natural resources. This can happen when, for example, unsustainable forest management lead to large-scale nutrient deprivation and soil erosion, when intensive agriculture is affecting water availability, or when overfishing is leading to the decline of ocean wildlife populations. Overconsumption can also increase the spread of invasive species, on purpose when new plant species are introduced in agriculture or forestry to fulfil upcoming consumer demand, or by accident, because the threat of invasive species is often intensified in disturbed habitat.
- **Energy use:** Energy use is spread all-over the consumption-production-system with clear impact on climate change, through GHG-emissions, and biodiversity loss, through mining and land-use changes, but also with possible effects on overexploitation when biomass demand for bioenergy exceed

biomass growing stock. Especially with an increasing demand for biomass, the biophysical limits have to be considered, as land used for agriculture and forestry cannot meet the competing demands for the provision of biomass and the conservation of biodiversity indefinitely (EEA, forthcoming).

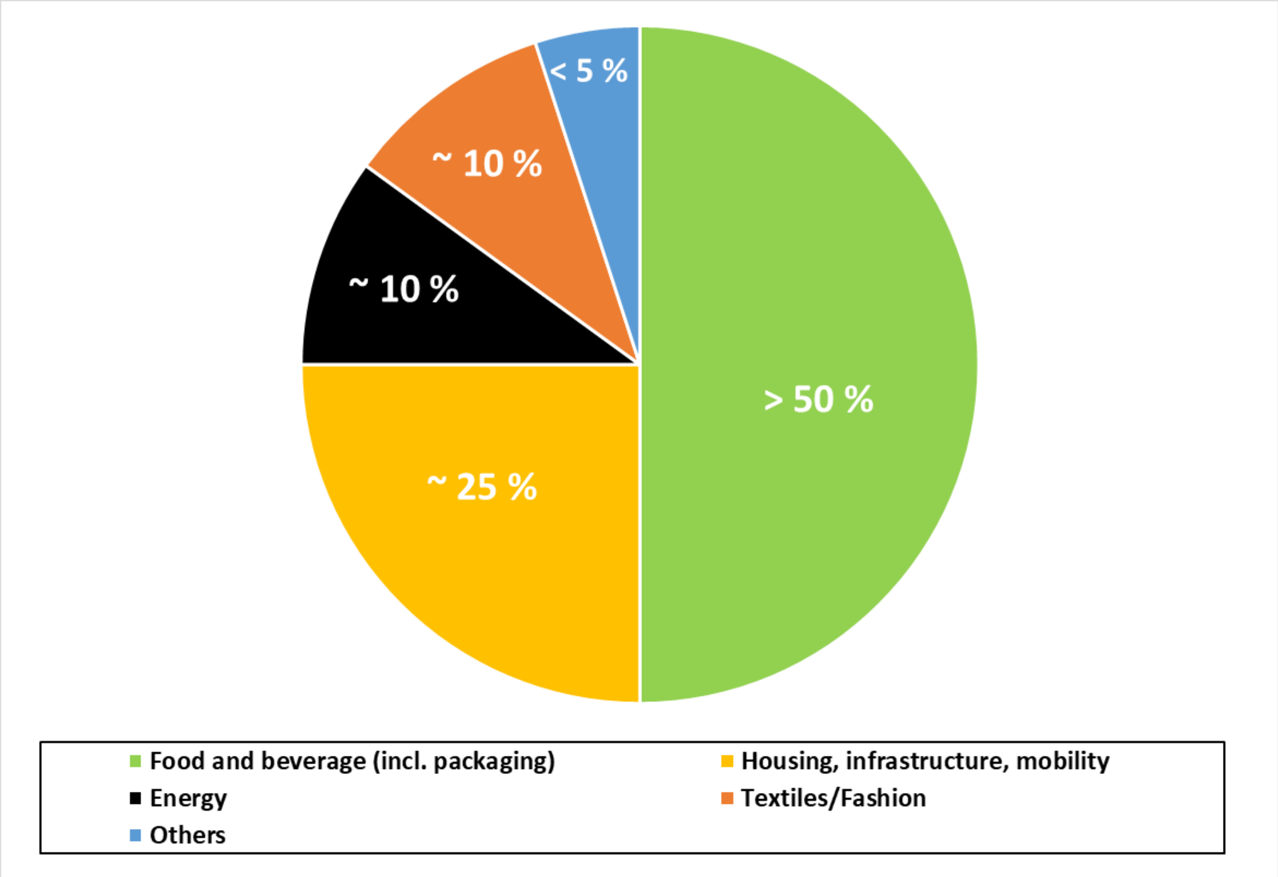
- **Waste & Emissions:** Almost every production process leads to emissions into the environment, from emissions in industrial process to fertilizers and pesticides in agriculture and forestry leading to contamination of species and pollution of ecosystems, but also contributing to climate change. In addition, most production sectors and consumption domains are generating wastes, which may lead to pollution if improper treatment occurs.

Those pressures have direct impacts on biodiversity, which can be summarised in three main groups, in addition to directly contribute to climate change and the spread of Invasive Alien species (Folk, 2021):

- **Habitat loss & ecosystem fragmentation:** Industrialisation has led to dramatic habitat destruction. Forests are cut down for their timber, terrestrial ecosystems are fragmented and destroyed to create roads, strip mines and gravel pits, etc. When applied to agriculture, industrialisation and investment in agricultural productivity has led to a continuous conversion of ecosystems to managed areas and to landscape homogenisation, affecting biodiversity at many scales (Benton et al., 2021).
- **Overexploitation & species extinction:** Our production and consumption practices are also resulting in direct or indirect overexploitation of natural resources and species. Direct when, for example, stocks of fish species are exploited well above their capacity to regenerate, or when the poaching of elephants for their valuable ivory and rhinos for their horns is putting those species at risk of extinction, indirect when the loss of natural and semi-natural habitats leads to plant and animal extinction, because species are unable to relocate or adapt to their new surroundings.
- **Contamination through pollution of air, water and soil:** air pollution is the biggest impact resulting from externalities of our production system, which is caused by the smoke and emissions generated by burning fossil fuels. Water pollution is also a major impact resulting from the production of goods and the generation of wastes, specifically in regions where factories, landfills and other waste disposal are built next to natural water sources. Toxins come in a variety of forms (solid, liquid or gaseous) and can all end up contaminating the local water supplies on the long term, before being gradually diluted in rivers and oceans. Soil contamination is another problem strongly linked to industrialisation, through heavy metal (the most common is lead) and toxic chemicals soil contamination, which can also leach into the soil and water tables and, in turn, contaminate any crop that grows in the surrounding. Brownfields can remain unusable for any other use for decades, while remediation techniques are expensive and still uncertain.

Looking more on the overarching picture of the consumption-production system as the driving force of biodiversity loss, the perspective of identifying key value chains, or consumption domains, helps to identify the hotspots of the most impacting activities. A recent study (Kurth et al., 2021) indicated that four consumption domains account for nearly 90 % of pressure on biodiversity worldwide: Food, Infrastructure and mobility, Energy and Textiles/fashion (Figure 2-4). The main impacts on biodiversity resulting from those consumption domains are described over the following sub-chapters (global figures and EU perspectives).

Figure 2-4: Value chains with highest pressure on biodiversity (based on Kurth et al., 2021)



Source(s): ETC/CE(based on Kurth et al., 2021)

The Food system

Global perspectives

Over the last decades, our food systems have been following the 'cheaper food paradigm', with a goal of producing more food at lower costs. This has led to increased inputs such as fertilizers and pesticides, as well as energy, land, and water uses. The current food system has created to a vicious circle, where a continues quest for 'cheap food' and lower and lower production costs resulted in increased intensification and continuous land clearance, on a global scale (Benton et al., 2021). Our global Agri-food system is now the primary driving force of biodiversity loss, the main direct pressure on water resources as well as a major driver of climate change, accounting for more than 30 % of total human-produced GHG emissions worldwide (Tubiello et al., 2022). More importantly, this recent analysis from the FAO shows the increasingly important role of food-related GHG emissions generated outside of agricultural land, in pre and post-production processes along food supply chains, at all scales. Still, agriculture alone is the identified threat to 24,000 of the 28,000 (86 %) terrestrial species at risk of extinction, according to the IUCN Red List of Threatened species[2]. Marine biodiversity is also under severe threat from unsustainable fishing practices for food production: around two-thirds of the world's fish stocks are either fished at their limit or overfished.

Aquaculture, an industry that has grown significantly in the past few decades to meet the demanding needs of the human food supply, has to some extent slowed the unsustainable practice of mass catching wild fish stocks. However, feeds for aquaculture are still largely made of fishmeal and oil, which in turn come from mass catching of wild fish. Yet, thanks to recent advances in food sources and species choice, aquaculture now globally uses about half a metric tonne of wild fish to produce one metric tonne of farmed seafood,

[2] https://www.iucnredlist.org/

meaning that aquaculture has a positive net production of fish protein. But most carnivorous species (e.g. salmon) do consume more fishmeal and/or fish oil then the weight produced as a final product. In addition, many of these cultured organisms can have a negative impact on the environment, first because of the proximity of the aquaculture infrastructures the open ocean and aquatic ecosystems and the possible invasion of escapees, but mostly through the discharge or organic matters and chemicals leading to eutrophication and contamination, as well as land take and coastal artificialisation, especially when installed in mangrove areas. Through these modes of disruption, aquaculture has the ability to drastically alter biodiversity and can resonate through multiple trophic levels, resulting in complete changes in the natural environment (UKEssays, 2018).

Situation in the EU

A study published in 2017 on the environmental impacts of a basket of food products identified as representative of the average food and beverage consumption in Europe (Notarnicola et al., 2017), showed that, for most of the impact categories, the consumed foods with the highest environmental burden are meat products (beef, pork and poultry), together with dairy products (cheese, milk and butter). And it is the agricultural phase in the lifecycle stages that has the highest impact of all the foods in the basket, due to the contribution of agriculture and breeding activities. Food processing and logistics are the next most important phases in terms of environmental impacts, in relation to their energy intensity and the related emissions occurring through the production of heat, steam and electricity and during transport. Moreover, it appears that pre- and post-production processes along food supply chains, at all scales form global, regional and nation have an increasingly important role of food-related emissions generated outside of agricultural land (Tubiello et al., 2022).

Deforestation, forest degradation and the conversion of ecosystems (such as savannahs and tropical forests) are key drivers of the climate emergency, and are also known to cause other severe environmental and social impacts. As such, emissions linked to deforestation constitute around one-sixth (15 %) of the total carbon footprint of food consumption in EU countries (Pendrill et al., 2019). Moreover, food wastes are occurring throughout the whole lifecycle of all food-related products, both at the agricultural/industrial level and domestic level. About a third of all food produced for human consumption worldwide is lost or wasted, generating about 8 to 10 % of global greenhouse gas emissions. Compared to national greenhouse gas emissions, food waste represent more emissions than any single country in the world, except China and the US (Eufic, 2021). In the EU, it is still around 10 % of food made available to consumers that may be wasted annually, while about 8 % of EU citizen cannot afford a quality meal every second day (Eurostat, 2022b).

Box 2 Key facts on impacts in the food system

- *Agriculture is the identified threat to 2,.000 of the 28,000 (86 %) terrestrial species at risk of extinction*
- *around two-thirds of the world's fish stocks are either fished at their limit or overfished*
- *about half a metric tonne of wild fish is used to produce one metric tonne of farmed seafood*
- *Consumed foods in the EU with the highest environmental burden are meat products (beef, pork and poultry), together with dairy products (cheese, milk and butter)*
- *The production processes along food supply chains have an increasingly important role of food-related GHG emissions*
- *About 10 % of food made available to EU consumers may be wasted annually*

Fashion and textile production

Global perspectives

Clothing is one of the most important human consumption domains, which demands are mostly met by a global and industrial production and manufacturing systems. The impacts on biodiversity at each level of the textile value chain are described below. The estimate of the magnitude of impacts is based on a report by IUCN, which has been reassessed by Granskog et al. (2020), and supported and enhanced by individual case studies, examples and further scientific references, adapted where possible to reflect the European component.

Factors that can influence the environmental impact of raw material production for textiles are different for natural and synthetic fibres, and include where and how crops are grown, or whether non-renewable resources are the foundation for the material. Natural fibres can be produced from cotton agriculture, forestry for cellulose production or animal farming for animal raw materials. Unsustainable cotton farming causes soil degradation from excessive water use, and habitat conversion/loss, degradation and fragmentation from agriculture expansion. In addition, about 200 tonnes of water on average are necessary to produce one tonne of cotton textiles (Derisi, 2016), which means that about 2.700 litres of water are needed to produce one T-shirt (WWF, 2014). Moreover, the cotton agriculture is responsible for 24 % of insecticides and 11 % of pesticides uses worldwide, despite using only 2.4 % of the world's arable land (Davis, 2003). It is also estimated that more than 150 million trees are logged annually for wood-based and man-made cellulose natural fibres (MMCF), and that up to 30 % of MMCFs may come from endangered and primary forests (Schultz and Suresh, 2017; Granskog et al., 2020). As for raw materials coming from animals and livestock farming, the main impacts on biodiversity are related to animal well-being, deforestation due to the use of land for pasture and feed grain production, as well as to water pollution from animal waste, antibiotics/hormones, fertilizers, etc. Natural fibres can also come from the hunting of wild animals, like with the Brazilian Bovine Leather imported by Italy (Mammadova et al., 2022), with consequences on wild population of the targeted species. The production of synthetic fibres (e.g. nylon, polyester, acrylic, and rayon) is associated with extremely high energy use**,** which has high impact on biodiversity. Indeed, while synthetic materials require less water than cotton, they use two to four times more energy (Putt del Pino et al., 2017).

Textile washing results in waterway pollution from microfibers and textiles is one of the key sources of microplastic pollution. It was estimated that around half a million tonnes of plastic microfibers shed during the washing of plastic-based textiles such as polyester, nylon, or acrylic end up in the ocean every year (Mishra et al., 2019). An estimated 35 % of primary microplastics in the world's oceans originate from the washing of synthetic textiles (Boucher and Friot, 2017) with many hazardous effects (including toxic chemicals) on marine aquatic species (Mishra et al., 2019). In addition, washing textiles also consumes a very high amount of energy and resulting emissions: it is estimated that 35 % of the lifetime CO_2 emissions of a cotton T-shirt occur during production, while 52 % occur during use/washing (Carbon Trust, 2011). Textile wastes have also high impacts on biodiversity, as 73 % of all textile wastes are incinerated or end up in landfills, which release pollutants into their surroundings and contribute to habitat loss. Anywhere from 30 to 300 species per hectare may be lost during the development of just one landfill site (Granskog et al., 2020). Only 12 % percent of textile wastes are downcycled (broken down into its component materials), and less than 1 % closed loop recycled (Ellen MacArthur Foundation, 2017).

Textile dyeing and treatment also have very high impacts on biodiversity. Apart from the large amount of water necessary, the type and volume of chemicals used for manufacturing, dyeing, and finishing garments are decisive when it comes to the impact on biodiversity. In terms of water use, the fashion sector requires 5 trillion litres of water for dyeing processes a year, in many cases drastically overexploiting local freshwater resources (Maxwell et al., 2015). Dyeing and treatment of textiles also cause chemical runoff and pollution through non-biodegradable liquid waste, being responsible for 20 to 25 % of industrial water pollution globally (World Bank, 2014; Granskog et al., 2020). The dyeing process can release up to 72 toxic chemicals into the local water supply (World Bank, 2014), with potential adverse effects on biodiversity. Of the 1.900 chemicals used in clothing production, the EU classifies 165 as hazardous to the health or the environment (Sajn, 2019).

Combining all activities across the value chain, the textile sector currently is responsible for about 10 % of GHG emissions globally (more than the emissions of all international flights and maritime shipping combined), but is expected to contribute nearly 26 % to global carbon emissions by 2050 (Putt del Pino et al., 2017). In the end, the textile industry generates more greenhouse gasses per unit of material than almost any other industry except aluminium (Kissinger et al., 2013). Cotton is gradually constituting less of the total fibre use, as particularly polyester becomes more common. Polyester production has gone from 5.2 million tonnes in 1980 to 19.2 million tonnes in 2000, and 54 million tonnes in 2017 (Carmichael, 2015; Niinimäki et al., 2020), and it is projected to rise to 71.6 million tonnes in 2030 (Angel et al., 2022). In 2010, synthetic fibres accounted for 60.1 % of fibres consumed, while cotton was at 32.9 % (FAO and ICAC, 2013).

Situation in the EU

On average, each European consumed nearly 26 kilograms of textile products in 2017 (ETC/WMGE, 2019). Most of the clothing and home textiles consumed in Europe are imported: 85 % of the primary raw materials used, 92 % of the water used, 93 % of the land used and 76 % of the greenhouse gas emissions caused by the production of textiles for European consumption occur elsewhere in the world (Köhler et al., 2021). As a result, textile consumption is one of the five consumption domains in Europe with the highest environmental impact in terms of primary raw material use, water use, land use and greenhouse gas emissions (ETC/WMGE, 2019).

Box 3: Key facts on impacts in the fashion sector

- *About 2,700 litres of water are needed to produce one T-shirt*
- *Synthetic materials require less water than cotton to be produced, but two to four times more energy: polyester production has gone from 5.2 million tonnes in 1980 to 54 million tonnes in 2017, and is projected to rise to 71.6 million tonnes in 2030*
- *Around 35 % of primary microplastics in the world's oceans originate from the washing of synthetic textiles*
- *73 % of all textile wastes are incinerated or end up in landfills, 12 % percent are downcycled (broken down into its component materials), and less than 1 % closed loop recycled*
- *The fashion sector requires 5 trillion litres of water a year only for dyeing processes, which is responsible for 20 to 25 % of industrial water pollution globally*
- *The textile industry generates more greenhouse gases per unit of material than almost any other industry*
- *85 % of the primary raw materials used, 92 % of the water used, 93 % of the land used and 76 % of the greenhouse gas emissions caused by the production of textiles for European consumption occur elsewhere in the world*

Infrastructure development (housing and transportation)

Global perspectives

Urban expansion is one of the most visible, rapid and irreversible types of land cover/land use change in contemporary human history, and a key driver of biodiversity loss (WWF, 2022b). Urban land, which includes the area used for residential, industrial, commercial and administrative purposes, as well as infrastructures (including transport) and urban open spaces (including planned open space like parks, and derelict space) only covers 0.2 to 2.4 % of the global terrestrial surface, but it has been one of the most radical driver of global land use change, leading to habitat conversion, degradation and fragmentation. Moreover, urban land is estimated to grow from about 1.1 million to 3.6 million km² by 2100, representing roughly 1.8 to 5.9 times the global total urban area occupied in the year 2000 (0.6 million km²) (Gao and O'Neill, 2020).

Global assessments showed that urban expansion has caused about 50 % loss of local species richness, and about 38 % loss of total abundance of species in intensively used urbanised areas compared to a naturally unimpacted land (Li et al., 2022). Transport infrastructure such as roads and railways also alter ecological conditions, by cutting through natural habitats and consequently reducing populations of many wildlife species, with ecological impacts extending into the adjacent landscape from few hundred meters up to 50 km (Benítez-López et al., 2010). Impacts of urban development can also be linked to the direct transformation and alteration of ecosystem functioning (e.g. the construction of dams and weirs in rivers and lakes, port infrastructure hindering coastal drift and sediment transport, etc.), as well as to source-related impacts from upstream rural or urban terrestrial areas (e.g. dispersal of solid waste or chemical pollution through inadequate waste and wastewater management; microplastic pollution through tire abrasion, etc.).

Certain urban areas can be considered as ecosystems, and are able to support a high variety of plant and animal species, including threatened species, and are increasingly recognised as important places for the conservation of biodiversity, including the greening of urban spaces and the creation of urban protected areas (Ives et al., 2016). Still, when humans alter natural habitats, many wild species cannot survive under the new conditions. In areas of high urbanisation, the remaining intact natural areas surrounded by human-disturbed land are often poorly connected between them, and too small to sustain viable populations of native species (Babí Almenar et al., 2019). As a result, the number and abundance of native wildlife species and population typically decline, as ecological generalist species that are better able to cope with altered conditions and thrive at the expense of habitat specialists (Habel and Schmitt, 2018).

In addition, come the more indirect impacts associated with material sourcing for infrastructure (e.g. steel, cement, iron, etc.), at all stages of the value chain. The construction industry is indeed the world's largest consumer of natural resources for raw materials (World Economic Forum, 2016). Sand and gravel account for about 85 % of all mining material on Earth today, and are the most consumed substances by humans after water. Sand and gravel are extracted from rivers, beaches and seabed (desert sand is functionally useless for construction purposes), at a quantity that is almost three times the amount of sediments naturally delivered to oceans by geologic processes (Hall, 2020; Torres et al., 2017). Those extractions represent more than 50 billion tonnes per year, and could double by 2060. China, for example, has used more sand every three years since the 2000's than the United States in the entire 20th century. Sand extraction, often undertaken illegally, does not come without impacts on biodiversity, especially in river ecosystems. As river sands have the right combination of shape and purity for a multitude of uses, some of the rivers in India are being so intensively mined that they are losing sand at a rate 40 times larger than the natural replenishment, leading to river beds dropping six feet over the past few decades (Klemetti, 2020). One avenue to reducing sand extraction is implementing a more rigorous recycling infrastructure and moving toward a circular economy for concrete.

Situation in the EU

Europe has faced more habitat fragmentation than any other continent (EEA, 2022c). Most of the natural and semi-natural ecosystems observed in the EU are extremely fragmented, cut to pieces by past and present urban sprawl, and a still rapidly expanding network of transport and energy. It is indeed estimated that 27 % of the terrestrial land in the EU is "highly fragmented", meaning that patches of natural and semi-natural habitats extent over less than 2 ha (EEA, 2022d). Nowadays, around 1,500 ha of mainly agricultural land are lost every day to infrastructure and urbanisation, an area equivalent to losing the entire agricultural land area of the Netherlands every three to four years.

European coastal and marine habitats are also increasingly being impacted by land-based activities, many of which are related to infrastructure development. The Dispersal of harmful substances from urban areas via air also has effects on all types of ecosystems (e.g. in urban areas, high rates of vehicle use in combination with low-density urban planning cause extreme air pollution due to ozone, which can affect sensitive vegetation and ecosystems, including forests). Spread of pollutants, as well as changes in nutrient loads and in biogeochemical cycles are also associated with housing and transportation infrastructures. Other direct biodiversity impacts from urbanisation include the increased risk of fire through housing development, especially in dry regions like around the Mediterranean Sea (Badia et al., 2011). Higher temperatures and light- and noise-pollution arising from activities associated with infrastructure development also impact surrounding ecosystems, by disrupting the natural cycles and dynamics of species (Sordello et al., 2020).

Non-native species thrive better in disturbed environment, and they can sometimes outcompete native species and become invasive in urban areas (Hulme, 2021). Long-range transport of construction raw materials and products facilitates the spread of invasive alien species, and especially maritime transport (shipping), in addition to being a source of waste and pollution (including noise) and physical damage to biota, e.g. from ship strikes or from large-scale catastrophic events such as oil spills (Walker et al., 2019). Activities such as landscaping, or private animal husbandry, can exacerbate these problems by introducing new species or promoting their dispersion (Santana Marques et al., 2020). Landscapes fragmentation by grey infrastructure, and especially linear infrastructures like highways and railways, also presents significant barriers to wildlife movements. Those infrastructures have a biodiversity footprint that far exceeds the physical imprint on the landscape (Seiler and Bhardwaj, 2020).

The contribution to climate change is also to be considered, with housing and transportation being particularly large emitters. In the EU, domestic transport was the second emitting sector and accounted for 22.2 % of CO_2 emissions in 2020 just after energy supply, while residential and commercial related emissions accounted for 13.4 %, behind the industry. International shipping and aviation accounted respectively for 3.7 % and 1.7 % (EEA, 2021b).

Box 4: Key facts on the impacts of infrastructure development

- *Urban land only covers 0.2 to 2.4 % of the global terrestrial surface*
- *It is still one of the most radical driver of global land use change leading to habitat conversion, degradation and fragmentation*
- *Transport infrastructure such as roads and railways can have ecological impacts from few hundred meters up to 50 km*
- *Sand and gravel account for about 85 % of all mining material on Earth today, and are the most consumed substances by humans after water*
- *They are extracted from rivers, beaches and seabed at a quantity almost tree time the amount naturally produced by geologic processes*
- *Those extractions represent more than 50 billion tonnes per year, and could double by 2060*
- *In the EU, 27 % of the terrestrial land is “highly fragmented”, with patches of habitats of less than two hectare*

Energy

Global perspectives

Energy production and use always have an impact on biodiversity, whether it is during the extraction of raw materials for energy production, the construction of energy power-plants or the generation of energy itself, like it is the case for fuel and coal combustion, the cooling of nuclear power-plants and waste disposal, or with wind turbine on flying wildlife. The main impact of the uses of fossil energy for electricity production, heat and as fuel in transport, is the production of high amounts of GHG emissions increasing climate change impacts on biodiversity, as well as the direct emission of other air pollutants. In addition, the extraction of coal, oil, gas, and other fossil fuels is harming terrestrial and marine ecosystems, and particularly deep-sea ecosystems (Jones et al., 2015). The direct impacts from oil spills on aquatic and marine ecosystems (e.g. Deep WaterHorizon, Exxon Valdez in Alaska), but also land ecosystems like pipeline leakages in the boreal forests of Siberia are also widely reported.

Even renewable energy sources can contribute to the loss of biodiversity and the disruption of ecosystem functioning (Pörtner et al., 2021). Following Bennun et al. (2021) habitat loss and fragmentation as well as bird and bat collisions are the predominant impacts associated with renewable energy developments In addition, the authors stated that about 17 % of large-scale (>10 MW) renewable energy facilities comprised of wind, solar (PV) and hydropower globally are operating within the boundaries of important conservation areas, including Key Biodiversity Areas (KBAs).

EU perspectives

In 2020, the EU produced around 42 % of its own energy, while 58 % was imported, with imports of oil, oil products and natural gas dominating. Because around 70 % of the energy consumed in the EU was covered by fossil fuels, with the share of renewable energy growing steadily (from 9.6 % in 2004 to 22.1 % in 2020 of the energy produced in the EU) (Eurostat, 2022a).
Still, only a careful and scientifically based planning for renewables development will ensure to minimise their negative effects on biodiversity. But mining activities on minerals needed for the construction of wind turbines or photovoltaic modules can also have significant impacts on biodiversity, in addition to the needs for the storage of electrical energy and the massive electrification of our uses, in particular transport.

Nuclear power generation also has impacts on biodiversity during normal production cycles (without mentioning the case of an accident), starting with Uranium extraction, which is done in about 50 underground and opencast mines located in 20 different countries, almost all outside the EU. The use of water for cooling also causes impairments of aquatic ecosystems, as the water released to the environment is significantly above ambient temperatures, especially during droughts and heatwaves.

Box 5: Key facts on impacts in the energy sector

- *The EU is producing around 42 % of its own energy, while 58 % was imported*
- *Almost 70 % of the energy used in the EU was covered by fossil fuels, dominated by imports of oil, petroleum products and natural gas*
- *The share of renewable energies among energy produced in the EU went from 9.6 % in 2004 to 22.1 % in 2020, leading both the increase of energy produced within the EU and the changes in energy production systems*
- *Mining activities needed for the construction of renewable energies infrastructure also have significant impacts on biodiversity, in addition to mining materials which are needed for the storage of electrical energy and the massive electrification of our uses, in particular transport.*
- *Uranium extraction is done in about 50 underground and opencast mines, located in 20 different countries almost all outside the EU*

2.4 Concluding remarks

The aim of this chapter was to provide a detailed overview of the main drivers of biodiversity loss in Europe, and its consequences on ecosystem functioning and services. In this context, the main drivers of biodiversity loss were examined, looking at the impacts of current production and consumption patterns in each of the domains with the greatest impact on biodiversity in Europe and beyond. It demonstrates that the extraction and cultivation of raw materials, especially in agriculture and forestry, is the major contributor to biodiversity loss. In addition, the processing of raw materials in the various sectors, also due to their energy requirements, contributes significantly to the pressure on biodiversity. This means that already at the beginning of the value chain of products and services, a significant contribution to the endangerment of biodiversity arises. But the way we deal with products, waste and emissions at the end of the value chain also has a major impact on the state of biodiversity. Thus, the entire production and consumption system and the entire value chain of products and services must be considered in order to minimise the pressure on biodiversity.

3 A more biodiversity-inclusive circular economy

The EU's current economy is still largely linear, based on the assumption that natural resources are abundantly available and cheap to dispose of. This paradigm has caused global resource extraction to increase from about 27 billion tonnes in 1970 to over 90 billion tonnes in 2017 (IRP, 2019). However, this way of working is not sustainable, as it exceeds several planetary boundaries, including the crucial boundary of 'biosphere integrity' which is closely linked to biodiversity loss (Steffen et al., 2015).

While the protection and rebuilding of biodiversity did not receive a lot of explicit attention in the early circular economy policy discourse, it has started to become somewhat more prominent in current policy documents. The European Green Deal puts more emphasis on circular economy's potential contribution to reversing biodiversity loss and rebuilding natural capital in Europe (European Commission, 2019), stating that '*About half of total greenhouse gas emissions and more than 90 % of biodiversity loss and water stress come from resource extraction and processing of materials, fuels and food.*' As part of the Green Deal, several new initiatives have been launched, some of which have an explicit reference to biodiversity protection, such as the Farm to Fork Strategy to transform the food system (European Commission, 2020d) and the Biodiversity Strategy for 2030 to tackle biodiversity loss and preserve ecosystems (European Commission, 2020c). In the 2020 CEAP the aim of the circular economy is defined as: *'To fulfil this ambition, the EU needs to accelerate the transition towards a regenerative growth model that gives back to the planet more than it takes, advance towards keeping its resource consumption within planetary boundaries, and therefore strive to reduce its consumption footprint and double its circular material use rate in the coming decade*' (European Commission, 2020a). One of the key value chains targeted in the CEAP is 'food, water, nutrients', which has a specific biodiversity focus. Additionally, in 2020 the Bellagio principles for monitoring the circular economy were published, developed by EEA and a number of countries, which explicitly refer to biodiversity as well (EEA et al., 2020).

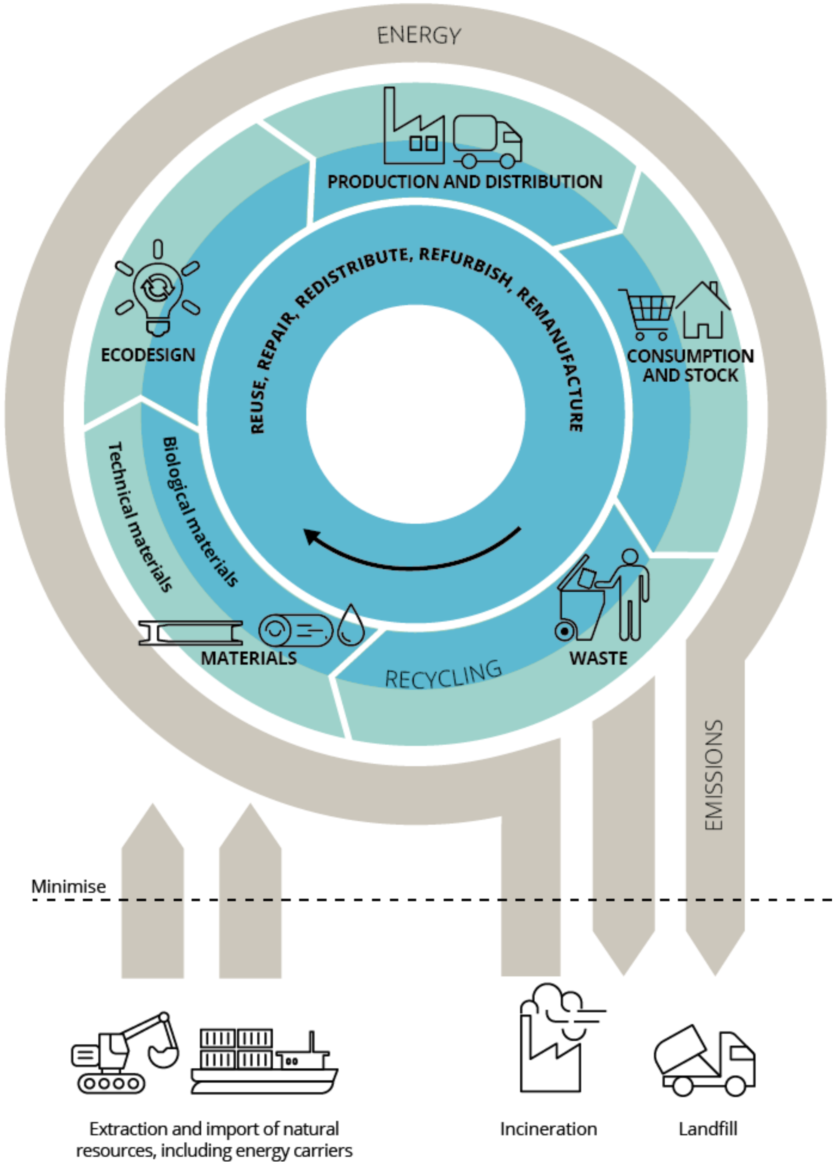
Circular economy will play an instrumental role in achieving climate-neutrality by 2050, in reducing pollution and in halting biodiversity loss. The circular economy's ambition of reducing resource extraction and waste generation could significantly contribute to reducing the pressures on the environment in general, which in turn would ease some of the key drivers for biodiversity loss (see Section 2.1). For example, reducing the demand for materials reduces the need for land conversion for mining, argiculture or forestry, which has a beneficial effect on habitat preservation, while reduction of waste also reduces pollution. Additionally, circularity is regarded as a way to reduce greenhouse gas emissions and climate change, as as thus an important contributor to achieving climate neutrality (European Commission, 2020a). On the other hand, despite its great potential, circular economy should not be regarded as a panacea for all environmental challenges.

This chapter explores how the circular economy can contribute to reducing drivers and pressures that cause biodiversity loss, i.e. by decreasing the resource use of our consumption-production system, and by eliminating and valorising waste. Potential limitations or trade-offs between circular economy strategies and biodiversity conservation are investigated to avoid pitfalls. Additionally, we will look into how circular economy can play a part in actively enhancing biodiversity by promoting regenerative practices and biodiversity-friendly sourcing, since – as it has been pointed out by the Ellen MacArthur Foundation (Ellen MacArthur Foundation, 2021b)- to achieve true biodiversity regeneration, we need to move beyond mere nature conservation towards real systemic change.

3.1 Core principles of Circular economy

The circular economy aims to keep materials and products in use for as long as possible, maximizing their value throughout their lifecycle and recycling them at the end of it (**Error! Reference source not found.**). A chieving a more circular use of materials is key to reducing the demand for virgin materials and improving resource efficiency (EEA, 2019b).

Figure 3-5: The Circular Economy



Source(s): (EEA, 2019b)

While Figure 3-5 differentiates between biological materials and technical materials, it does not propose different pathways for each of these resource types, nor does it include pressures on biodiversity. Yet, biological and technical resources have different properties, different sustainability challenges and – which is the focus of this report - a different impact on biodiversity loss. The pressures related to technical resources will be predominantly linked to habitat destruction and pollution from mining operations, the emission of chemical substances to water, soil and air during manufacturing and the generation of hazardous and non-degradable wastes that can end up in the environment. Alternatively, the pressures related to biological resources will be mostly linked to agriculture and forestry, and their associated land use changes, management practices, use of agrochemicals and management of biowastes. This could entail land use change from natural land and forests to cropland or plantations, destroying habitats, pollution from agrochemicals or overexploitation of soils and fishing grounds. The different pressures related to biological and technical resources is particularly relevant in the light of the current strategies to fight climate change, which often entail the replacement of fossil (technical) resources by biomass (biological) resources. While such replacement may reduce carbon emissions, it may also entail additional land use changes to accommodate the need for more agricultural land, or the conversion of natural forests to plantations of industrial crops. That way, trade-offs may arise between different drivers of biodiversity loss, such as climate change and land use change.

Although the original concept of circular economy, as described by the Ellen MacArthur Foundation, included a clear difference between technical and biological cycles of circular economy (Ellen MacArthur Foundation and McKinsey Center for Business and Environment, 2015), the technical cycle clearly gets the most attention in the circular economy discourse. In literature, many circular economy frameworks use a set of R-words to express different circular economy strategies applicable to the technical cycle. While the number of R-words differs between sources (Henry et al., 2020), the most simple and well-known variant is probably the 3R-framework – 'reduce, reuse, recycle' – based on the waste hierarchy. Other authors have extended the framework with additional R's to better describe and distinguish between the broad variety of strategies that the circular economy has to offer, e.g. Potting et al. (2017) lists up to 10 R's. A common feature of these R-word sets is that the different R-strategies are considered to be hierarchical, with strategies associated with prevention of material use and waste regarded as more desirable (e.g. refuse, reduce), and strategies associated with waste treatment as least desirable (e.g. recycle, recover). Still, it is agreed that a circular economy needs a combination of all these strategies to successfully manage resources and waste. While some frameworks explicitly include the aspect of 'nature regeneration' (Ellen MacArthur Foundation, 2021b; Forslund et al., 2022), the overall circular economy discourse tends to focus strongly on technical resources, leaving specific challenges related to the sustainable use of bio-based resources often underexposed. Yet, the mere fact that a material is bio-based does not necessarily mean that it is sustainable, nor circular (EEA, 2018b).

Bio-based resources play a key role in our economy, and especially in the shift towards a low-carbon economy. Still, there is a cap on how much biomass can be produced in a sustainable way. Therefore, the development of the bioeconomy needs to be done in a sustainable and circular way (EEA, 2018b), with the protection and rebuilding of biodiversity at its heart (Buchmann-Duck and Beazley, 2020; Schröder et al., 2021). The concept of the 'circular bioeconomy' combines the principles of both circular economy and bioeconomy, acknowledging that biological resources need to be sourced in a sustainable way and managed in integrated cycles of cascading material uses, before moving to other uses such as the production of chemical feedstock, fuels or biogas through digestion processes. Eventually, nutrients need to be returned to farmland in order to preserve soil quality and productivity (Ellen MacArthur Foundation and McKinsey Center for Business and Environment, 2015). Keeping biobased resources at their highest possible value by increasing product lifetimes, smart cascading and the valorisation of biowastes is key to get as much value as possible out of the biomass we use and eases the pressure on land use (Stegmann et al., 2020).

Acknowledging the fact that the bioeconomy has its own sustainability challenges, the general circular economy discourse should devote more attention towards biodiversity-friendly sourcing and circular management of bio-based resources.

3.2 Circular economy's contribution to halting biodiversity loss

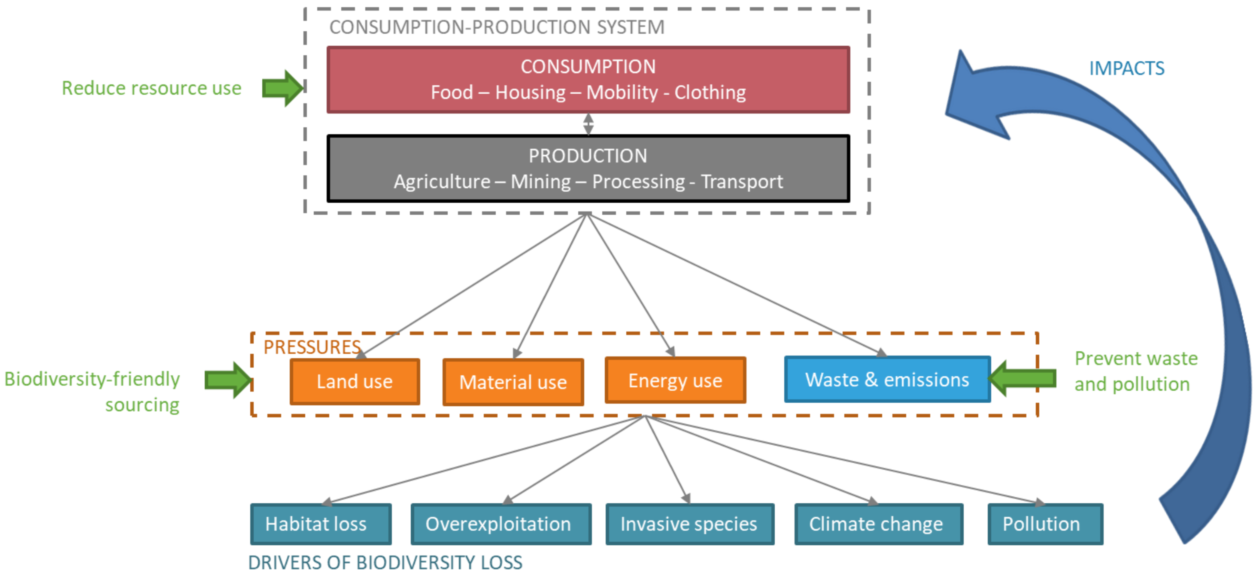
In the current report, we bring together the realms of circular economy and biodiversity by exploring the contribution that circular economy could bring to halting biodiversity loss. The Global Biodiversity Outlook points out several areas of action that could reduce or -when combined- even reverse biodiversity loss, such as (1) reduced consumption, (2) more sustainable production of goods and services, (3) reduction of key biodiversity loss drivers including pollution, invasive species and overexploitation, (4) climate change mitigation and (5) enhanced conservation and restoration actions (Secretariat of the Convention on Biological Diversity, 2020, p. 13).

With its ambition to reduce resource use and waste, by recirculating products and materials in the economy, the circular economy could directly contribute to all these actions. Decreasing the use of natural resources, decreases the pressure to initiate mining or excavation activities in new areas or to convert natural habitats into additional cropland or plantations. As a result, habitat loss, overexploitation and the introduction of invasive species (e.g. planting of cash crops at the expense of natural vegetation) will be eased. By eliminating waste, pollution is prevented. More indirectly, circular economy can also contribute to climate change mitigation since longer product use and recycling generally emit less greenhouse gases than virgin production.
Although, biodiversity conservation and restoration arguably fall somewhat outside, actions related to how resources are produced (i.e. sourcing practices) clearly should fall within core circular economy activities as they can contribute to more resilient ecosystems, reducing and stopping biodiversity loss and the restoration of ecosystems, creating sustainable and more resilient production systems.

In conclusion, those strategies that are typically considered to be at the centre of circular economy (Reuse, Repair, Recycling) mainly affect the quantities of resources, land, materials and energy that are extracted in order to produce goods and services, as well as the emissions that accompany extraction, production, use and end-of-life. On the other hand, the qualitative aspects of resource extraction and ecosystem management (i.e. biodiversity-friendly sourcing practices) are less at the centre of CE strategies. For example, CE strategies can reduce the demand for wood, but have more of an indirect influence on the way how forests are managed. Since both aspects affect the pressure on biodiversity by forestry – and other sourcing industries- there is a clear need to incorporate both the quantitative and the qualitative aspects into our reading of circular economy, in order to make it a suitable framework for biodiversity protection and regeneration.

Figure 3-6 shows in a schematic way how circular economy principles affect consumption-production systems, and subsequently reduce those systems' pressures on the environment in general, and -consequently- on the drivers of biodiversity loss in particular. In the next sections, each of the circular economy approaches will be discussed in more detail.

Figure 3-6: How CE can affect the drivers of biodiversity loss



Source: ETC/CE and EEA

3.3 Reduce resource use

Our current production and consumption systems rely heavily on the use of primary natural resources, exerting a pressure on the environment and biodiversity. In 2015, the World Resources Forum has estimated that the demand for natural resources exceeded 41 % the spare capacity of Earth, and projections are showing that if the demand and population continues to grow at the current that, the equivalent of two Earths will be needed to satisfy it by 2030 (World Resources Forum, 2015). Moreover, the rate at which materials are being extracted globally is outpacing both population and economic growth, which means that we are using more materials and less efficiently (One Planet Network, 2021).

To decrease dependence on resources, both supply-side and demand-side measures are needed. We need to rethink our production processes to move away from resource intensive and wasteful manufacturing processes. While circular alternatives on the market – enabled by policies and businesses – are essential, (over)consumption habits at a consumer level need to be addressed in parallel to ensure that we reduce our resource consumption as effectively as possible. More resource-efficient consumption behaviour needs to be encouraged, for example by developing circular business models supporting it. Product design is a key connector in reducing production pressures and supporting sustainable consumption. By adopting design practices that support longer use, enable repair and facilitate recycling at end of life, linear production-consumption systems can be transformed into circular systems that reduce the need for resource extraction, by preserving value for as long as possible.

Resource-efficient manufacturing processes

Sustainable manufacturing processes aim to produce goods with minimum use of energy and natural resources, while ensuring societal health and safety throughout the product life cycle (Kumar and Mani, 2021). **Resource-efficient manufacturing,** reducing material, energy and land use, has a direct effect on biodiversity drivers, such as habitat loss, overexploitation and climate change. Moreover, it also reduces the generation of production waste and corresponding pollution, as well as the pollution directly linked to the production of goods itself.

Since land-use change is the largest driver of biodiversity loss, major attention needs to go to those sectors that have a large land footprint, due to the cultivation of biomass in the form of food and feed, natural fibres, wood and biofuels. It is estimated that 85 per cent of land-use related biodiversity loss is due to biomass cultivation, with feed production for livestock (e.g. soy) being the most impactful (Forslund, 2021; Green et al., 2019). However, other sectors also contribute to biodiversity loss through land-use change and pollution resulting from mining activities, transport and the discharge of production emissions.

Apart from efficiency improvements that lower overall material use, using low-impact materials, such as recycled or renewable materials, can help to reduce the environmental impact of resource use. Using **recycled materials** as a replacement to virgin materials not only reduces the need for mining activities (land-use and pollution), but also saves on energy use needed to process and refine those materials, which reduces the emissions leading to climate change. For example, the production of recycled aluminium only requires 10 % of the energy needed to produce virgin aluminium (Ingarao, 2017). In the textiles industry, several jeans brands are experimenting with the use of recycled denim fibres in new garments to reduce environmental pressures, such as water use, land use. MUD jeans claims that their production of 1 pair of jeans, using 40 % recycled fibres and extensive water recycling processes, saves 93 % water, 74 % CO_2 emissions, 47 % land use and 51 % biodiversity loss compared with industry standards (Mud Jeans, 2020).

Shifting from fossil-based sources to sustainably sourced **renewable materials** is often proposed to reduce environmental impacts, in particular climate change impacts, of resource use. Within European Climate Policy, there is considerable attention for the role of bioeconomy in reducing greenhouse gas emissions, by replacing non-renewable and fossil-fuel derived products with bio-based alternatives (European Commission, 2022a). Examples are the use of biofuels in transport, wood pellets for heating and bio-based plastics to replace conventional fossil plastics. However, the challenge of using alternative materials is the risk of trade-offs. Many authors have raised concerns about the sustainability of the bioeconomy since it requires intensive land use which can be detrimental for biodiversity and ecosystem services if not done sustainably (d'Amato and Korhonen, 2021). A shift to bio-based resources could increase competition with other land uses such as food production and aggravate the pressure to transform more natural habitat into arable land and wood plantations, while risking overexploitation of existing croplands and forests. Since the current European bioeconomy is already highly dependent on cropland abroad to supply its demand for agricultural products, a further uncontrolled increase of biomass use will increase land use pressures both inside and outside Europe (O'Brien et al., 2015).

Therefore, to ease the pressure on land use, the bioeconomy also needs to be material efficient. Using second generation feedstock, such as biowaste or harvest residues, could alleviate some of these trade-offs (EEA, 2018b, 2020a). Moreover, R&D efforts explore the use of microalgae as a third-generation biomass feedstock for a variety of chemicals (Ben-Hamadou, 2017). Microalgae have the advantage that they can be produced on non-arable land, in seawater or in wastewater, reducing arable land-use and competition with other crops (Trivedi et al., 2015).

Reducing (over)consumption

Reducing (over)consumption is the priority action to reduce resource use and will consequently reduce waste generation as well, thus easing the pressures on land use and habitat loss, overexploitation and pollution which affect biodiversity loss. Reducing consumption is considered a challenging endeavour in the light of the current economic reality, in which companies rely on overproduction and ever-increasing sales, thus encouraging their customers to frequently buy new stuff and get rid of old items, even though they are still functional or repairable. The fast fashion movement is often regarded as exemplary for encouraged overconsumption and the generation of waste (House of Commons, 2019). In fast fashion, styles change fast, and clothing items are produced using lower-quality materials and sold at cheap prices. The phenomenon of fast fashion is fairly recent. Around 2000, fashion brands typically released two seasonal clothing collections per year (Koszewska, 2018). Nowadays, some large brands are releasing 12-24 collections every year (Remy et al., 2016). This overconsumption of fashion goes together with a decrease in clothing lifespan. More than half of our wardrobe is discarded within three years (Greenpeace, 2015). Overproduction and encouraged overconsumption through discounting (e.g. Black Friday) are a core issue of the fast fashion paradigm. Only about a third of fashion items are sold at full price, while another third is sold in sales and the remaining unsold stock is discarded (SITRA and Circle Economy, 2015).

The idea of reducing (over)consumption and changing lifestyles is often referred to with the term '**sufficiency**' in the environmental discourse (Linz et al., 2002; Princen, 2005; Stengel, 2011). The idea broadly demands that people limit their consumption to a degree that is needed for 'a good life', not entailing 'too much' harmful emissions and resource extraction. In the example of fashion, 'slow fashion' is proposing an alternative, trying to convince consumers to buy fewer clothes, made of high-quality durable materials and long-lasting styles. The main challenge will be to find suitable business models that keep fashion affordable and brands profitable (Gillabel et al., 2021).

Using products for longer reduces the need to buy new products, and thus saves on resource use and associated environmental and biodiversity impacts. Extending product life times is estimated to be more environmental beneficial than recycling, or even reuse (Heidenstrøm et al., 2021). By reducing consumption, longer product lives also indirectly reduce energy use and emissions during production and transport, which in turn reduces the need for resource extraction and associated environmental and biodiversity impacts. For example, extending the life of garments by nine extra months has been estimated to reduce carbon, water and waste footprints by 20 to 30 % (Cooper et al., 2013). The design phase of products is crucial in enabling longer product lives. Longer product lives do not only involve choosing high-quality and durable materials, but also applying a design facilitating easy maintenance and repairability (EEA, 2022f; ECOS, 2021). It also entails repairability and availability of accessible and affordable repair services and spare parts. Moreover, it requires a culture shift among consumers, moving away from a culture of following latest trends and fast disposal towards emotional durability, making users willing to use products for longer, maintaining, upgrading and repairing them (van den Berge et al., 2021; Makov and Fitzpatrick, 2021).

Shifting consumption towards more sustainable products is a way to decrease resource use and associated environmental impacts, without necessarily reducing overall consumption levels. Examples are the shift from meat-based to plant-based diets to reduce land use for food production, the choice to buy local products to reduce transport emissions or the choice for products made from recycled materials instead of virgin materials. For consumers, making sustainable choices is not always easy. Several labelling systems exist, such as energy labels and the EU ecolabel, that aim to provide information to consumers to support sustainable choices.

Circular business models can play an important role in enabling and encouraging more sustainable consumption behaviour (Gillabel et al., 2021), which in turn helps to slow material use and ease the effect on associated biodiversity loss drivers. Business models that support longer product lives are key (Forslund, 2021; EEA, 2021a; ETC/WMGE, 2021). Making repair or refurbishment services available, accessible and affordable help extending product lifetimes (e.g. reselling of refurbished smartphones). The set-up of take-back schemes for used goods (e.g. vouchers for used clothing, refunds for reusable/recyclable packaging) create incentives to sort and return products for reuse or recycling. Shifting from ownership models to as-a-service models could reduce the number of products lying around unused in attics, cellars, garden sheds and garages, allowing more users to benefit mutually from fewer goods. For example, co-housing initiatives with shared facilities could reduce land use for housing, while making housing more affordable. Service models could also help to facilitate a more sustainable lifestyle by 'unburdening' users, like for example in the case of energy-saver services that help reducing energy-consumption in private homes or public buildings (Peñate-Valentín et al., 2021). This kind of shifting could be even more impactful in the transport sector. Indeed, the current growing trend in shared-mobility practices is likely to reduce by a third the expected increase in vehicle sales by 2030, while it is estimated that shared mobility currently only makes up about 1% of the 30% of annual vehicle miles travelled that it could address (Grosse-Ophoff et al., 2017).

3.4 Prevent waste and pollution

Today's economy is extremely wasteful, in particular because it is based on a 'linear' economy. For Europe, it is estimated that around 88 million tonnes of food is wasted per year, mostly during distribution and consumption, corresponding to about 227-304 million tonnes of CO_2 equivalent (Vittuari et al., 2016). Likewise, one third of all clothing items produced is not sold, but just ends up as dead stock (SITRA and Circle Economy, 2015). In addition to the loss of valuable resources, waste generation during production and consumption can take the form of non-degradable litter and microplastics, hazardous emissions such as toxins, or nutrient losses causing acidification, eutrophication or other types of pollution. Pollution is a big driver to biodiversity loss (section 2.1).

Waste is largely a flaw in product design and current production processes, which means that it is possible to avoid waste generation by conceiving products and processes differently, in addition to reducing production itself. By designing out waste and eliminating the use of hazardous substances during product design stage, waste generation and pollution at end of life can be prevented. It also avoids contaminating recycling streams. Alternatively, unavoidable waste should be properly managed, so it does not end up polluting the environment. Instead, it should be valorised and reintroduced in the economy by collection, sorting and recycling systems, by setting up industrial symbiosis that use waste as a resource in other value chains, by nutrient-recovery processes (e.g. fermentation and composting) or, if that is not possible, by recovering the embodied energy in combustion or fermentation plants. These principles already enshrined in EU waste legislation through the waste hierarchy, but not yet fully implemented.

Designing out waste

Many inefficiencies in our economy are linked to throwing away products too soon. Many current business models build on making profit from short product lifetimes and quick replacements, such as in fast fashion. There can be several technical reasons for premature discarding of products: product failures, wear and tear, impossibility to clean or repair or out-datedness. For many of these issues, choices made during the design stage are determining the end-of-life options that are available. Resource-efficient designs could thus support a decrease in material use, while **circular design** strategies, such as *design-for-durability*, *design-for-ease-of-maintenance-and-repair, design-for-dis-and-reassembly* and *design-for-recyclability* (Bakker et al., 2014; Bocken et al., 2016), could enable longer product use, repair and eventually, better recycling.

One of the initiatives of the European Commission related to extending product lives is the establishment of a 'right to repair', which has been announced in several of the European Commission's strategic documents: the European Green Deal, the new circular economy action plan and the new consumer agenda. Better access to repair activities (professional as well as DIY) saves costs for consumers and facilitates the development of a circular economy (Šajn, 2022) (Box 6).

Box 6: The 'Right to Repair'

To facilitate longer product lives through repair, repairing needs to be more convenient, more affordable, and more desirable than simply buying a new replacement. Product design is key here, as a product's repairability is conceived at the design stage. Design-for-repairability has several aspects (Bocken et al., 2016). First of all, products need to be intended for a long product life:

1. Design for physical durability: choose durable materials, prevent breakdown due to wear and tear
2. Design for emotional durability: making sure consumers get attached and want to keep the product, rather than throwing it away.
3. Design for ease of maintenance: making it easy to keep the product in good shape during use
4. Secondly, repairs and replacement of parts need to be enabled by:
5. Design for dis- and reassembly: parts should be easy to remove and replace, without the need for special tools. For those cases where repair of individual components would be too difficult or unsafe, modules should be replaceable, e.g. battery packs.
6. Design for upgradability and adaptability: allowing future expansion or modification when technologies or conditions change
7. Design for standardisation and compatibility: allowing the use of the same parts in multiple products

Furthermore, a 'right to repair' implies that repairs are convenient, either by brands offering a repair service, free of charge during the legal guarantee period, or at an affordable cost and convenience after the legal guarantee period. Alternatively, consumers can also be empowered to carry out repairs themselves, by making spare parts available and providing an easy-to-use repair guide with accessible instructions. However, under EU law manufacturers are only obliged to provide technical repair instructions and spare parts to professional repairers (and for some products), but not to consumers (Šajn, 2022).

The EU 'right to repair initiative' is expected to involve amendments to several directives, such as the Sale of Goods Directive, the Consumer Rights Directive and the Ecodesign Directive (Šajn, 2022). The proposal for the Sustainable Products Initiative contains information requirements, which could be included in a product passport (next to non-digital manuals and labels). These requirements will also include clear and understandable technical guidelines that should enable repairers, consumers and other end-users to install, use, maintain, repair and safely dispose of the product.

Phasing out the presence of hazardous chemicals also contributes to designing out waste, reducing emissions and avoid leakages (EEA, 2022g). Pollution from chemicals and waste is one of the major drivers of biodiversity loss (IPBES, 2019). Many products contain hazardous substances to boost their performance, such as flame retardants in electronic equipment (to improve fire safety), heavy metals in paints or plasticizers that make plastics more durable and flexible. These substances are often persistent and bioaccumulate in living organisms, which means that even small amounts can cause significant environmental impacts and health problems in the long term. However, not only do these substances present health risks during production, when these products become waste, but the hazardous substances in them can also present an obstacle for reuse or recycling, which may become more complex, more expensive or even impossible. An additional problem is that recyclers often cannot know exactly which chemicals are present in the waste they receive for processing. This poses the risk that hazardous or banned substances pollute recycling streams and material cycles, posing a risk to human health or the environment, or causing batches of recycled materials to be lost for reuse.

For example, persistent organic pollutants (POPs) are hazardous chemicals that affect human health and the environment. They are used in waterproof textiles, furniture, plastics and electronic equipment. When these products become end-of-life, the POPs end up in the waste. POPs are highly toxic, they persist or take decades to degrade and they accumulate in fat tissue of living beings. Studies have linked POP exposure to the declines, diseases or abnormalities in a number of wildlife populations, including fish, birds and mammals (US EPA, 2014). Especially predator species that are at the top of the food chain are at risk. POPs are thought to have a multitude of adverse effects on reproduction, immunology, endocrine and neurological functions. Humans are exposed mainly through contaminated food and the POPs can be transmitted through the placenta and breast milk. The European Parliament has recently decided to introduce value limits to further restrict the presence of these chemicals in waste (Delpero, 2022).

The European Chemicals Strategy for sustainability aims to contribute to EU's zero pollution ambition, as part of the Green Deal. It aims to ban or phase out the most harmful chemicals in consumer products, such as per- and polyfluoroalkyl substances (PFAS), allowing their use only where essential (European Commission, 2020b). The product design stage is crucial here: if products would be designed not to include such substances of concern, clean material cycles for circular economy would be easier to achieve, and the risk of unwanted spreading of polluting substances would be decreased.

High quality recycling

High-quality recycling both prevents waste ending up in the environment, causing pollution or eutrophication - which is a key driver of biodiversity loss in marine environments-, while at the same time saving virgin resource extraction as recycled materials can be used in new production, reducing extraction-related environmental and biodiversity impacts.

Also, for bio-based material waste (biowaste), proper waste management, including recycling, is crucial. If not managed well, biowaste poses significant environmental threats such as methane emissions, which is a powerful greenhouse gas, from decomposing (EEA, 2020a) and eutrophication, due to uncontrolled discharge of nitrogen and phosphorus. Eutrophication highly affects aquatic ecosystems, causing algae bloom proliferation, which reduces water clarity and quality, reducing light penetration and eventually causing oxygen depletion (Chislock et al., 2013), altering behaviour of organisms (Lehtiniemi et al., 2005) and causing biodiversity changes and loss among plants and animals (Wang et al., 2021; Alexander et al., 2017). Some algae blooms, for example by cyanobacteria, produce noxious toxins that affect water quality, fisheries and pose health risks (Chislock et al., 2013).

An important component of biowaste is food waste, representing about 60 % of the total municipal biowaste in the EU-28 (EEA, 2020a). Next to prevention of avoidable food waste, non-avoidable biowaste needs to be transformed into valuable resources. High-quality recycling processes entail a combination of **cascading material use** (e.g. food waste to feed, wood waste to construction boards, biowastes to chemical feedstock), composting and **energetic utilisation** by fermentation (Fricke et al., 2017). Regular application of good-quality compost improves soil structure, water and nutrient retention, carbon storage and microbial biodiversity, adding to soil fertility (EEA, 2020a).

The **separation of biowaste at source** is a prerequisite for high-quality recycling of biowaste (Schüch et al., 2019). In 2017, about 43 % of municipal biowaste was collected separately, while the remainder ended up in mixed municipal waste and was thus lost for recycling (EEA, 2020a).

3.5 Biodiversity-friendly sourcing

Circular economy principles can clearly play a role in reducing pressures on land and resource use and thus can contribute to easing biodiversity loss. Although essential, resource-efficiency and waste prevention alone will not guarantee that biodiversity loss is halted and degraded areas are restored (Ellen MacArthur Foundation, 2021b; Forslund et al., 2022). To achieve this, a reduction in resource consumption needs to go hand in hand with active biodiversity conservation and restoration efforts and biodiversity-friendly sourcing. In particular, a transformation of our food system that is the main driver to land use change (Leclère et al., 2020). The ultimate ambition of a sustainable society would be, not only to reduce negative environmental impacts, but to become 'nature-positive'[3]. Biodiversity-friendly sourcing should therefore be thought of in steps-wise approach, where first efforts are made to ensure that circular economy activities pose no (significant) harm to nature, second that circular economy activities support nature conservation, and third that they (when possible) enable regeneration. It is important to consider all the steps focus to avoid the risk of jumping straight to regenerative actions, while 'overlooking' the importance of no-harm to nature and nature conservation.

Production systems should not only be circular in terms of resource use and waste minimisation, but they should have biodiversity protection and regeneration at their core, in every step of the value chain and throughout all circular strategies. Such ambition would not only entail production practices that avoid or reduce nature and biodiversity loss, but these processes should also support nature regeneration to a level that allows full recovery. To make this possible, underlying consumption and production systems that drive the rate of nature and biodiversity loss need to be fundamentally transformed, e.g. through technological innovation or conversely improved traditional knowledge, economic incentives, institutional re-organisation and changes in underlying social structures, values and behaviours (Science-based targets Network, 2020). For example, regenerative agriculture aims to combine food and material production with nutrient retention, soil conservation, water management and carbon sequestration, while avoiding harmful chemical inputs (Ellen MacArthur Foundation, 2021b). This requires alternative, old and traditional varieties of crop species, and different farming methods including perennial and cover crops, reduced tillage, mulching, mixed cropping and crop rotations and sustainable pest management, most of them inspired by ancestral practices improved by new scientific knowledge.

Yet, the regenerative dimension of the circular economy does not receive a lot of attention in the dominant circular economy discourse, nor is it included in the well-known R-frameworks describing the ladder of circular strategies based on the waste hierarchy. Still, it is clear from the ambitions in the Green Deal and the CEAP that *'EU needs to accelerate the transition towards a regenerative growth model that gives back to the planet more than it takes.'* (European Commission, 2020a). Still, it is clear that biodiversity-friendly sourcing, based on regenerative practices, is a crucial prerequisite for biodiversity protection. While the R-frameworks of circular economy typically illustrate how we can reduce the negative environmental impacts of resource use and pollution - Reduce, Reuse and Recycle -, there is a clear need to make Regeneration an explicit boundary condition in the discourse.

---

[3] 'Nature-positive' refers to an approach that goes beyond the mere reduction or avoidance of environmental impact, instead aiming to actively improve ecosystem resilience, by enriching biodiversity, storing carbon, purifying air or water.

Regeneration aims at improving ecosystem productivity and resilience within existing agricultural, aquaculture and forestry systems. Regenerative practices improve soil health, water and nutrient retention and crop diversification with a focus on native species and spatial and temporal heterogeneity (Chazdon and Guariguata, 2016; Forslund et al., 2022). As a result of regenerative practices, ecosystems under economic exploitation become resilient against external shocks and disturbances, and in particular against climate change, and may flip from a state of ecosystem degradation to a state of ecosystem improvement (Schröder et al., 2021).

Conservation biology and restoration ecology are well-established scientific disciplines aiming to retain the Earth's biodiversity in the face of human activities and their impacts on the environment, and both are intended to bridge the gaps among science, practice, and policy. Especially in Europe, both nature conservation and restoration are involving active management practices. Still, conservation is usually about preserving the least degraded places and ecosystems, offering the greatest potential for maintaining or enhancing biodiversity at lower costs, while restoration is often designed to recover at least some of the utilitarian values of ecosystems (Wiens and Hobbs, 2015).

It is true that the cost of restoring an ecosystem is generally higher, uncertain and deals with already degraded habitats. But when resources and opportunities for meeting conservation needs are limited, restoration practices are imperative to provide additional benefits, in addition for ecosystems to continue providing natural resources in a sustainable way. Therefore, biodiversity-friendly sourcing incorporates both, measures to avoid and reduce biodiversity loss (e.g., through secondary raw material use and good mining management), as well as practices aiming at ecosystem regeneration and restoration (e.g., through regenerative agriculture) (Forslund et al., 2022).

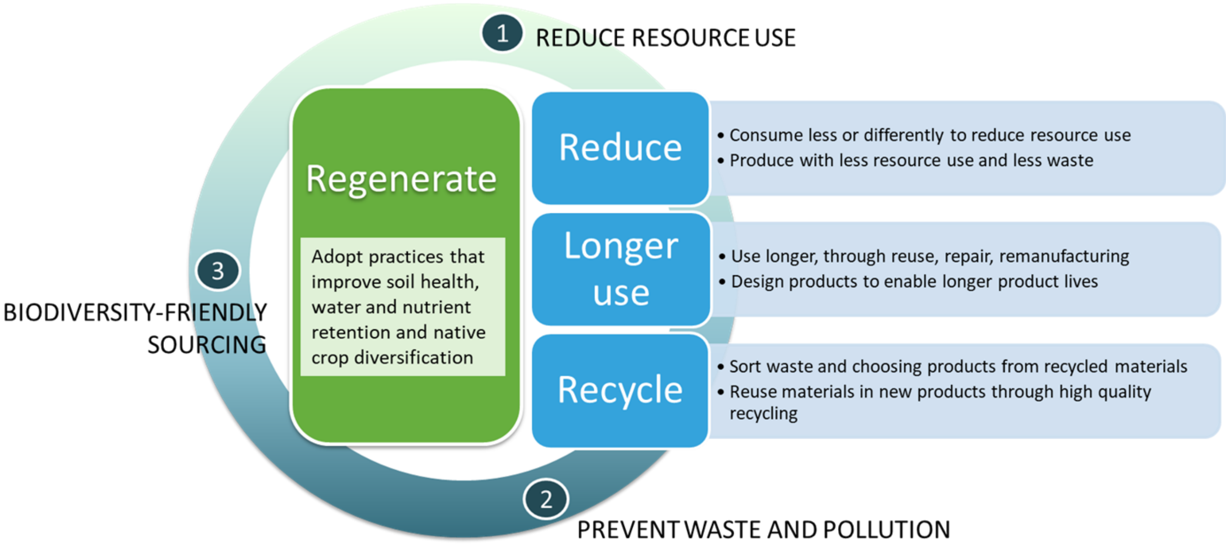
3.6 Conclusion

This chapter aimed to investigate how circular economy measures can help protecting and rebuilding biodiversity. By maintaining the value of products, materials and other resources in the economy for as long as possible, enhancing their efficient use in production and consumption, and returning them into the product cycle at the end of their life, circular economy measures reduce the need for resource extraction and reduce the amount of waste, which is generally beneficial to both biodiversity and climate. These two principles are commonly covered when discussing circular economy inventions, they are enshrined in the R-frameworks and are well targeted by policy.

However, while CE measures (directly and indirectly) contribute to meeting biodiversity and climate/energy strategic objectives, circular strategies alone cannot be considered a panacea for biodiversity challenges. To assure a positive effect of circular economy strategies on biodiversity, explicit attention should be devoted to biodiversity-friendly sourcing as well. This third principle, however, is often overlooked in CE policy, or taken for granted. This principle not only aims to reduce negative effects, but also aims to generate positive biodiversity outcomes. In addition to approaches to biodiversity protection and restoration, e.g. in the context of mining management, it entails the adoption of regenerative production practices across all stages of the product value chain, especially in production processes involving agriculture, aquaculture and forestry. Here, it focuses on nutrient retention, soil conservation, water management and sustainable pest management. A recent study by Finnish Innovation Fund (Sitra) has modelled that a circular economy built around regenerative production principles can halt and even partly reverse biodiversity loss by 2035 by, amongst others, reducing land use demand (Forslund et al., 2022). To achieve this, the authors put forward far-reaching reductions in resource use and waste generation, in combination with a wide-spread adoption of regenerative production principles in agriculture, pasture management and forestry. Drastic behavioural changes will be needed to reduce resource use, induced by suitable business models and policy-led interventions, such as longer product lifetimes, drastic improvements in use efficiency, further densification of cities and a significant reduction in meat and dairy consumption and food waste generation. The study concludes that, in their scenario, a circular food and agriculture sector would contribute by far the most to biodiversity recovery (73%, two thirds of which would be due to a major shift in diets to alternative proteins), while buildings and construction, fibres and textiles, and forests contribute 10 %, 9 % and 8 %, respectively (Forslund et al., 2022). In other words, if the circular economy should contribute to biodiversity, it has to address the food and agriculture sector with a focus on innovative management systems, reducing food waste and switching to alternatives to animal protein.

In sum, circular economy solutions with biodiversity-friendly sourcing are needed alongside conservation efforts to bend the curve on biodiversity loss (Forslund et al., 2022). For this reason, we propose an adapted circular economy framework, which integrates regeneration as an underlying principle: a biodiversity-inclusive circular economy (Figure 3-7). The biodiversity-inclusive circular economy consists of three core principles: (1) Reduce resource use, (2) Prevent waste and pollution; and (3) Biodiversity-friendly sourcing. This can be linked to the R-frameworks by adding a fourth underlying boundary condition 'Regenerate' to the traditional hierarchy of 'Reduce', 'Longer use' and 'Recycle' so the bio-economy is explicitly considered. This last element also includes notions of promoting no-harm to nature principles and to operate in line with conservation and restoration efforts.

Figure 3-7: A framework for a biodiversity-inclusive circular economy



Source: ETC/CE (EEA, 2022; ETC/CE, 2022)

In conclusion, while CE measures (directly and indirectly) contribute to meeting biodiversity objectives, the combination with biodiversity-friendly sourcing is crucial in order to achieve this ambition. A narrow reading of circular economy as the idea of closing cycles alone will not suffice as it does not touch on the question on how large and fast such cycles can be (Desing et al., 2020), nor how sustainable the material inputs are.

4. Examples of circular economy actions to promote biodiversity

The previous chapters have demonstrated that a fundamental transition in consumption and production systems is crucial to move away from overproduction, overconsumption, inefficient resource use and high environmental impact. Efficient production processes and circular business models that focus on the use of low environmental impact resources and circular design should reduce overall resource use and waste generation while supporting longer product lifetimes and promoting sustainable consumption patterns that emphasise sufficiency, prolonged use, reuse, repair and environmentally conscious choices. In this way, the pressure on that causing biodiversity loss can be alleviated and turned into opportunities to actively promote biodiversity. Based on the finding in chapter 2 that around 90 % of the pressure on biodiversity can be traced back to four key value chains, the following chapter will use concrete examples to show which circular economy approaches can contribute to reducing biodiversity loss in these main areas.

4.1 Food

As mentioned in chapter 2, food and biomass production is a major contributor to loss of biodiversity and ecosystem services. About half of the world's habitable land is currently being used for agriculture and nearly two-thirds of all species are threatened by agriculture and aquaculture (Paajanen et al., 2021). Large scale habitat losses occur due to land use change caused by food and feed production as well as the clearing of land for cattle pasture. Some of the most biodiverse regions of the world are facing critical pressures from current agricultural practices, with 42 million hectares of tropical forest in Latin America lost due to cattle ranching in the period from 1980-2000 (Benton et al., 2021). The increased inputs of fertilizers and pesticides as well as energy and water use further exacerbates the sectors harmful impacts on both climate and biodiversity.

There are several interrelated interventions needed to address the biodiversity losses stemming from the food system. A Chatham House report (Benton et al., 2021), supported by the UN Environment Program (UNEP) and Compassion in World Farming, describes three actions needed for food system transformation in support of biodiversity, and sets out recommendations to embed food system reform in high level political events over the coming UN 'Super Year' for Nature. According to this report, a reform of food systems is a matter of urgency and should focus on three interdependent actions:

Firstly, global dietary patterns need to move towards more plant-heavy diets, mainly due to the disproportionate impact of animal agriculture on biodiversity, land use and the environment. Such a shift, coupled with the reduction of global food waste, would reduce demand and the pressure on the environment and land, benefit the health of populations around the world, and help reduce the risk of pandemics. The Farm to Fork strategy (EC, 2020c) aims to tackle both challenges as it addresses sustainable food consumption towards a more plant-based diet which will reduce the environmental impact of the food system and the need for farmland for feed production, potentially freeing up natural space for increased biodiversity. The strategy also aims to reduce food loss and waste which minimises the need for overproduction in the primary sector and reducing its impact on biodiversity.

Secondly, more land needs to be protected and set aside for nature. The greatest gains for biodiversity will occur when we preserve or restore whole ecosystems. Therefore, we need to avoid converting land for agriculture. In addition to a dietary shift, pressure on land can also be reduced on a transitional basis by identifying and using alternative sources for feed production. Here, insect-based protein sources have emerged as a possible alternative to plant proteins in recent years. By using raw materials already contained in the production system, such as agricultural or food waste, the pressure on biodiversity from intensive land use and land use change or exploitation of marine resources can be reduced. In addition, waste can become higher value products. If, as in the Nasekomo example (Box 7) or EntoGreen (EU, 2019), organic fertiliser is also produced as a by-product, this can also contribute to the regeneration of the nutrient balance of soils and soil biodiversity.

Box 7: Nasekomo

Nasekomo: Organic residues upcycling through insect bioconversion
Founded: 2017
Origin: Bulgaria
CE framework: Reduce resource use, Prevent waste and pollution, Regenerate

Nasekomo is a company based in Bulgaria that uses insects (specifically Black Soldier Flies) to produce sustainable insect protein for feed and aquaculture systems and fertilisers for agriculture.
Nasekomo mainly uses agricultural waste to produce insect-based, high-protein feeds using black soldier flies. Whole insect larvae as well as insect meal and oil are offered as feed and feed supplements. This can be used in pet food as well as in chicken and pig farming and aquaculture. In addition, nutrients are returned to agricultural land through the production of an insect-based fertilizer.

Biodiversity benefits
The advantage for biodiversity is twofold. Firstly, the use of agri-organic residues to produce protein-rich animal feed reduces land-based production of fodder. The use of insect meal in aquaculture can have an additional positive effect on wild fish by reducing the use of fish meal. This reduces the pressure on biodiversity from feed production. Secondly, the second product is an organic fertiliser that can be used to regenerate soils and reduce the use of industrial fertilisers.

Source: https://nasekomo.life/

And thirdly, according to Benton et al. (2021), farming activities need to be more nature-friendly and biodiversity-supporting, by limiting the use of inputs and replacing monoculture with polyculture farming practices. Circular agriculture , or “nature-inclusive” agriculture (Runhaar, 2017), is a form of sustainable agriculture based on a resilient food and ecosystem, meaning on the optimised use of biomass in closed loops where possible, and closing the nutrient cycles (United Nations Department of Economic and Social Affairs, 2021). It is not a new concept, but can be rethought. Fodder production adapted to livestock and use of manure and slurry for nutrient-adapted fertilisation are also traditional practices for less waste and closed loops in agriculture as the use of catch crops and perennial crop rotations contribute to nutrient regeneration and to some extent regenerate biodiversity. New or rethought practices and concepts of circular agriculture and food production like regenerative farming, hydroponics, aquaponics and urban agriculture demonstrate how one waste stream of one supply chain can be the raw materials for another. The reNature case (Box 8) is one such example of how circular and regenerative agricultural practices can further biodiversity. Regenerative agricultural practices is an approach to managing agroecosystems that provides food and materials in ways that create positive effects for nature and help regenerate degraded ecosystems and build resilience on farms. By closing nutrient cycles, they may improve soil quality. By offering different habitats local biodiversity will be fostered and higher levels of carbon sequestration can be reached (Ellen MacArthur Foundation, 2021b).

Box 8: reNature

reNature: Scaling the positive impact of regenerative agriculture
Founded: 2018
Origin: The Netherlands
CE framework: Regenerate

reNature is a Netherlands-based company that aims to promote regenerative agriculture globally. Through this, the company aims to regenerate 2 % of agricultural land by 2035. Projects to date have been implemented mainly in the global South, but initial projects have also been launched in Europe. reNature develops model farms, small farms that aim to grow one or two main crops in an agroforestry system, which are used to demonstrate and enable people to experience the system of regenerative agriculture. In addition, reNature is hosting regular courses in their model schools where farmers can learn from other farmers. They also offer transition packages for larger projects at landscape level by providing technical assistance, monitoring and evaluation and stakeholder engagement to access premiums for regenerative products and carbon credits for farmers and communities.

Biodiversity benefits
The regenerative agroforestry systems that reNature designs can create multiple benefits for biodiversity. By using a multi-plant system with different layers, the on-site biodiversity is increased in comparison to traditional one or two crop systems. Furthermore, this creates several micro-habitats with favourable conditions for other non-planted species, animals and soil microbiome. The resulting improvements in soil fertility, combined with the ability of these systems to produce more food on the same amount of land, help reduce pressures on land-use change. Additionally, the promoted agroforestry system sequester more carbon than conventional production systems.

Source: https://renature.co

Marine organisms, such as microalgae, fish and invertebrates, are an important source of food and biochemicals. In the case of food, aquaculture may largely cater for the increasing demand for fish. Its proportion of production is rapidly increasing and is projected to cover an estimated 60 % of total demand by 2030 (World Bank, 2013). This expansion of the aquaculture sector is not without environmental challenges, which are rather similar to those faced in agriculture in relation to intensive livestock production. The demand for feed puts pressure on other (feedstock) species and causes nutrient issues in coastal zones. Disease transfer to wild populations is also an associated risk (EEA, 2017). Whereas disease transfer could be address by good management practices, the pressure on feedstock species may be reduced by substitutes for fishmeal (e.g. see Box 7). The increase nutrient input can be minimised through good management. At the same time, combined systems such as aquatic biorefineries offer a nutrient management option.

An aquatic biorefinery is based on aquaculture and includes marine, freshwater and dryland fisheries, and the algae industry. Designed as a regenerative and circular ocean farming system, it can underpin biodiversity while providing nutritious food for human consumption. In addition to producing resources for the food and feed industries, aquaculture can also provide aquatic biomass for other industries and end uses, such as the production of biofuels, chemicals and nutrients and the extraction of dietary supplements, such as omega-3 oils, from fish waste and algae.

Box 9: The Seaweed Company

The Seaweed Company: Regenerative and sustainable seaweed farming
Founded: 2018
Origin: Netherlands
CE framework: Regenerate

The Seaweed Company grow and harvest different types of marine algae in seaweed farms in Ireland, Morocco, India and the Netherlands. The dried seaweed is transformed in a variety of products like food and feed as well as bio-based fertilizers. In addition, The Seaweed Company offers with its "Blue Impact Program" carbon removal credits and foster regenerative agriculture. As part of the programme as well as one of the main products of The Seaweed Company, bioactive compounds are extracted from the seaweed and turned into a bio-stimulant called "TopHealth Plants", which should help the plants to be more resilient to biotic and abiotic stress such as pests and diseases, and resistance to heat, frost, flooding, salinity, and drought. In addition, better root structure and development can be achieved, and soil structure and soil biodiversity is expected to increase.

Biodiversity benefits
The growth of seaweed helps to regenerate local ocean ecosystems by absorbing carbon dioxide, nitrogen and phosphorus. Seaweed requires only sunlight and naturally occurring marine nutrients to grow, meaning no inputs including land, fresh water or fertiliser are needed. While growing, seaweed also forms a habitat for marine life and enriches marine biodiversity and Studies have also shown that in general, growing seaweed can enhance water quality and absorb nutrient run-off, with the production of 500 million tonnes (~ 453.6 million tonnes) of seaweed having been estimated to be able to assimilate 10 million tonnes (~ 9.1 million tonnes) of nitrogen from seawater, equalling some 30 % of the nitrogen estimated to enter the ocean (Bjerregaard et al., 2016).

Source: https://www.theseaweedcompany.com/

Nutrient recycling can be supported by converting residues and organic waste from aquaculture into biogas and agricultural fertilizers. The biogas can then be transformed into biofuels, power or heat, for example to heat a nearby greenhouse (c.f. Sybimar in Finland (Mikkola et al., 2016)). This way, an industrial symbiosis cluster can be organised around aquaculture, so that all raw materials are fully used in a wide variety of products.
For many value chains in an aquatic biorefinery, it is essential that the aquatic feedstock harvesting and the biorefining installations are located close to one another, as the raw materials need to be fresh when processed. This means that aquaculture biorefineries have a positive effect on local job creation.

4.2 Infrastructure development (housing and transportation)

Currently, infrastructure and buildings are designed, developed and organised in a mostly linear way leading to a significantly environmental impact. Globally, the construction sector is responsible for more than a third of global material resource consumption, including 12 % of all freshwater use, and significantly contributes to the generation of solid waste (UNEP, 2011). The EU construction industry and the respective construction and demolition waste streams waste accounts for approximately 37 % of all waste generated (Eurostat, 2022c). Furthermore, the construction industry is responsible for approximately 36% of the EU's greenhouse gas emissions and buildings stand responsible for 40 % of the total EU final energy consumption (EEA, 2022b). In addition, the expansion of towns and cities and infrastructure development is major driver on land-use change. For example, the use of greenfield land for shopping malls, commercial zones, and housing tracts has significantly increased over the past three decades, an evolution influenced in large measure by people's ever-growing use of cars and ever-growing mobility. All this contributes to the drivers of biodiversity loss. Land use change and overexploitation of natural resources through extraction of construction materials and soil sealing, pollution along the whole life cycle of buildings and infrastructure, climate change through the high amount of energy consumption and GHG-emissions.

Following the EU's circular economy action plan (European Commission, 2020a), which include the built environment as a priority sector, an increase in the circularity in construction help to avoid or delay the use of new buildings and construction materials and its respective environmental impacts. Three circularity objectives are mainly relevant in the construction sector: (i) increasing existing buildings' life span and the use intensity of buildings, (ii) reduce the need for material consumption through actions aiming at resource efficiency and (iii) the use of materials with higher circular potential (EEA, 2022b). All three approaches can be implemented in both new construction and renovation of the existing building stock.
Measures of these three objectives mainly have an effect on reduced biodiversity impacts through the reduction of resource use, partly also through the avoidance of waste. In addition to the savings in (primary) construction materials, the reduced energy demand and the resulting savings in greenhouse gas emissions are also relevant, as they address the negative effects of climate change on biodiversity. If these measures are integrated and supplemented by other measures or embedded in a broader overall concept, they can also contribute to regenerate biodiversity.

Increasing life span and the use intensity of buildings

By 2050, it is estimated that the average lifetime of buildings can be extended from 64 years to 91 years by using circular models. This would mean around a 30 % lower long-term demand for new constructions (ETC/WMGE, 2020). This in turn would save construction material and avoid soil sealing and land-use change. In the EU Member States, on average 45.4 % of the residential buildings were built before 1969 and 75.4 % before 1990 (European Construction Sector Observatory, 2018). This means that repairing, refurbishing, and retrofitting of existing buildings plays a crucial step in extending the lifetime of buildings in the EU.

In addition, new builds and refurbishments need to be done in a way that ensures they are adaptable (for multiple use), reversible (modular design) and adhere to circular principles. A long-lasting building is often the result of good **design for durability**, choosing and designing structural elements that last as long as the building does. A second issue to be considered already in the design phase of new buildings are later adaptations and transformations of buildings and their use. Such a **design for adaptation** ensures a longer lifespan for buildings by improving its ability to adapt and respond to shifts in market demand. Considering concepts such as modular units and moveable interior walls or modularity already in the design phase, will allow to downsize a home or an office, or supporting sharing and mixed functionality leading to an efficient and effective use of a building during its lifetime.

In the built environment, so-called nature-based solutions can increase the lifespan of the building envelope, improve urban biodiversity by providing habitats and food, and offer ecosystem services, such as water management, pollination and climate regulation in highly urbanised environments (Johnson, 2019; Lin et al., 2015; Pearlmutter et al., 2020). Green roofs can, in some cases, double the lifespan in comparison to conventional roof constructions due to an improved protection against harmful weathering and intense sunlight (Calheiros and Stefanakis, 2021). Green facades also play a similar role by reducing the maintenance requirements of conventional facades due to the protective layer against sunlight and high temperatures. Furthermore, green roofs and facades function as natural insulation of the building envelope reducing the demand for man-made insulation material and decrease the energy demand needed for heating and cooling of buildings. In addition to reducing energy consumption and subsequent greenhouse gases, greening the building envelope may lead to carbon sequestration and uptake of air pollutants such as nitrous oxide, sulphur oxide and particulate matter, with positive effects for halting biodiversity loss (Johnson, 2019).

Box 10: Potsdamer Platz, Berlin

Potsdamer Platz, Berlin – Circularity for storm water protection and water treatment
Founded: 1998
Origin: Germany
CE framework: Regenerate, Reduce resource use

In the redevelopment of Potsdamer Platz in Berlin, particular emphasis was placed on contributing to the green and blue urban infrastructure and reflect a water sensitive urban design with a building-integrated water recycling system. On an area of 30,000 square meters an entire system of connected green roofs is used to absorb precipitation and drain it into a large underground cistern system. The water is used for topping up the urban pools in the surrounding of the buildings, for flushing toilets in offices and for irrigating green areas. Water treatment is chemical-free and energy efficient. Solid particles already settle in the cisterns. The water then flows from the cisterns via infiltration systems into the urban water basins made of planted water biotopes, which serve for biological purification. If necessary, additional filters can be used in the summer months to remove suspended algae from the water. The water is aerated in a series of multi-layered structures as it passes through the pools.

Biodiversity benefits
The green roofs and the water biotopes in the urban pools numerous offer habitats for plant and animal species. In addition, carbon sequestration can be realised and abiotic construction material for the roofs were saved. The on-site water treatment with biological purification saves energy and through water reuse drinking water is saved. In addition, the urban pool system improves the urban climate, since the water slightly lowers the ambient temperature in summer, binds dust particles and humidifies the air.

Source: https://www.urbangreenbluegrids.com/projects/potsdamer-platz-berlin-germany/
https://www.greenroofs.com/2017/06/17/greenroofs-com-project-of-the-week-june-19-2017-potsdamer-platz/

Material Economics (2018) stated that much of European office space is occupied only for 40 % of the time, showing that there seem to be a huge potential for intensify the use of existing buildings. The recent IPCC report says that, "at a global level, up to 17 % of the mitigation potential [in the building sector] could be captured by 2050 through sufficiency interventions" (IPCC, 2022, pp. 9-4), wherein sufficiency intervention include multi-functional spaces and shared spaces. Sharing of only partly used business space e.g., through **co-working spaces** is increasingly practiced. A concept similar to co-working is that of **co-housing** in which housing is seen as more than merely the sum of apartments. Cohousing, in general, describes a housing model, whether in flats, freestanding houses, duplexes or whole blocks) where a group of people intentionally agree to work together to create a place where they can all live close to one another – independently in their own separate 'homes' – but sharing certain things as part of a broader community venture (Westerholm, 2020). The key element is that the parties agree to (and actively want) to share certain aspects of their lives. The worldwide first co-housing community is Saettedammen (Denmark), established already in 1972. Saettedammen consists of 27 houses, several of which are divided, plus a large common room and a community house offering a laundry, kitchen, games room and soft play room. The houses themselves are built using a modular design, using a single load-bearing ceiling beam runs through the entire house, allowing the non-load-bearing, interior walls to be moved around according to living needs. The combination of shared rooms/space and modular design of houses reduce the demand for settlement area and construction material and therefore lower the pressure on biodiversity associated to soil sealing and raw material extraction. In addition, the further sharing of typical household goods, like washing machines, and infrequently used devices and tools reduce the demand for such goods and products.

Reduce the need for material consumption

Several circular economy measures exist which either reduce the demand for primary material and its interlinked environmental impacts or which decrease the need for construction material at all.
Using construction and demolition waste in high-grade products, meaning as materials or components used in structural elements of a building or infrastructure with high durability, would avoid downcycling and lead

to savings of materials. Following ETC/WMGE (2020) ideally half of concrete waste could be recycled in high-grade applications, resulting in 20 to 30 % of virgin material can be substituted by waste material in several applications. Replacing virgin concrete, with high embodied energy and CO_2 emissions in production, will on the one hand reduce the pressure on biodiversity by reducing the impact on climate change. On the other hand, substitution of primary concrete with recycled material will lower the demand of primary raw materials, like gravel and sand, and its associated impacts on biodiversity, e.g. by land-use change and changing water regimes. The increased use of secondary materials should always be coupled with strategies for lifetime extensions of buildings. Using by-products from other sectors (industrial symbiosis) or reusing and recycling existing materials other than construction and demolition waste (see Box 11) , to produce innovative construction materials is a further measure to reduce primary raw material demand (EEA, 2022b).

Box 11: Greenful

Greenful Panels
Founded: 2019
Origin: Estonia
CE framework: Reduce resource use, prevent waste and pollution

Recycling textile waste, used plastics and used car tires to produce construction materials is the innovative approach of Greenful. The Greenful Panel, a strong load-bearing panel from textile fibres and proprietary composite material, can be used for internal or external construction as it is fire-resistant and may replace wood-based construction panels. Greenful SIP Panel, a sandwich panel made of a foam insulating layer with textile fibres between two Greenful Panels, is used for wall paneling. And Greenful EcoTile, a conglomerate material of textile fibres, plastic and shredded tyre rubber mixed with glue, can be used for paving pavements and other surfaces replacing asphalt and concrete. All panels are being recyclable, the products are eco-friendly, with no pollutants or toxic chemicals used. Greenful vision is to recycle 10 % of the total waste generated Europe-wide by reprocessing of over 300,000 tonnes of textile waste every year

Biodiversity benefits
Using secondary raw materials like textile waste instead of concrete allowed the construction process to reduce its dependence on the extraction of finite resources like sand and gravel, which are associated with detrimental effects to biodiversity. In addition, CO_2 emissions are reduced. Further, by replacing wood-based construction panels unintended side-effects on biodiversity like illegal logging and deforestation may be avoided.

Source: https://greenful.com/

Whereas increasing the recycled content of construction materials can be implemented in new construction and renovation, the design phase of buildings offer further options, e.g. with a **design for disassembly** that takes the total lifecycle of products into consideration and where a building is seen as a material storage (ETC/WMGE, 2020; Westerholm, 2020). Buildings and construction elements are design in a way that they are easy to disassemble into their individual components, so that they all can be reused, reassembled, reconfigured or recycled, thus extending their useful life. Appropriate use of reversible technologies like bolts, nuts, clip systems, screws or even lime mortars instead of nails, glues, welded solutions or cement mortars is key to facilitating and increasing the future reuse of components in the construction sector (ETC/WMGE, 2020). Design for disassembly provide considerable raw material savings and helps to reduce a building's total environmental lifecycle impacts related to the preservation of embodied energy, the reduction of carbon emissions and pollution and therefore may have positive effects on biodiversity (Debacker and Manshoven, 2016). The Brummen Town Hall (Ellen MacArthur Foundation, 2022) or the gugler media company circular flagship building (BusinessEurope, 2019) are innovative concepts in this regard.

The substitution of abiotic construction materials, mainly concrete and steel, with renewable raw materials is often seen as a main measure lowering the environmental impact of the construction sector, mainly through reduced GHG-emissions and reduced extraction e.g. of sand, gravel, and other finite resource of which are associated with ecosystem disruption. **Timber** is seen as an interesting alternative to concrete and steel, offering the co-benefit of carbon storing and reduced material demand per capita (Churkina et al., 2020). In addition, using timber as construction material provide good opportunities for disassembly, e.g. mechanical fastenings, allowing for better re-use of construction element and an easier recycling (Forslund et al., 2022; Ellen MacArthur Foundation, 2021b). Albeit, potential shorter lifetimes than steel is something to factor in.

Substitution with renewable raw materials, on the other hand, may also have unintended side-effects, especially on biodiversity due to intensified land use and land-use changes. Illegal logging and deforestation as well as forest land conversion to monocultural silvicultural system may lead to negative effects on biodiversity, when timber construction is scaled-up without strong legal and political commitment on protection and sustainable management of forests (Forslund et al., 2022). Sustainable forestry with mixed stands, sufficient amount of habitat trees and deadwood and low impact on forest soils can limit habitat disturbance, reduce erosion, and improve soil health and carbon storage in forests.

To minimise possible negative effects associated with land-use in biomass production, the use of innovative bio composites based on agricultural waste could be a solution. Such materials can combine the advantages of renewable raw materials over conventional construction materials, like GHG-emission savings and carbon storage, and recycling by exploiting agricultural by-products (Pearlmutter et al., 2020). An innovative bio-composite building material based on agricultural waste was developed by Ricehouse using by-products of rice cultivation and lime products to produce pre-fabricated construction frames and construction materials (see Box 12)

Box 12: Ricehouse

Ricehouse - Rice for architecture
Founded: 2016
Origin: Italy
CE framework: Reduce resource use, prevent waste and pollution

Ricehouse's mission is to build the rice house, everything from the micro to the macro using by-products from the rice supply chain. To realise this vision, Ricehouse developed a diverse line of building products derived from the use of agricultural and industrial rice processing waste from insulation materials and components over thermal-acoustic insulation of the base layers of horizontal surfaces, outdoor flooring systems to prefabricated construction blocks or blends for 3D printing. By using waste from rice production, the innovative concept also holds great potential for global expansion, as rice is grown and processed on five continents.

Biodiversity benefits

Using by-products and waste from agriculture instead of concrete allowed the construction process to reduce its dependence on the extraction of finite resources like sand and gravel, which are associated with detrimental effects to biodiversity, e.g. by reducing habitat loss and overexploitation of natural resources. In addition, CO_2-intensive products like cement and steel are substitute by bio-based products offering potential for CO_2 storing during the entire life-span.

Source: https://www.ricehouse.it/

Spatial planning and infrastructure development

Circular Economy measures can be applied not only at the level of buildings or building complexes and with reference to the use of raw materials, but also at the level of spatial planning and urban development.

The expansion of towns and cities and infrastructure development is major driver on land-use change and the accompanying loss of biodiversity. For example, the use of greenfield land for shopping malls, commercial zones, and housing tracts has significantly increased over the past three decades, an evolution influenced in large measure by people’s ever-growing use of cars and ever-growing mobility. However, at the same time, structural change has resulted in an increasing amount of inner urban brownfields. These brownfields provide space that can be revitalised for new uses, because they are often well integrated into existing infrastructures. **Brownfield re-use and inner urban development** thus represent circular economy measures that lower the need for new land in particular, reduce the increase in soil sealing and decrease the need for materials for infrastructure development. This reduces the pressure on ecosystems and biodiversity, and these areas can be made available for renaturation in high-quality green and blue spaces. This could offer a 'triple win' by mitigating environmental pollution and supporting biodiversity as well as improving the health and well-being of urban populations (EEA, 2019a). In order to promote this, however, relevant framework conditions must also be changed. Municipalities are in a tough location competition, especially for new business settlements and the influx of new residents. Demands and expectations of the users of building land, such as the size of the plot or the hoped-for quality of living, are frequently at stake.

In addition, to the reuse of settlement areas, the consideration of circular economy aspects in the planning of unavoidable new land uses for infrastructure, industrial parks and residential areas represents another important lever for reducing the consumption of resources. **Densification around mass-transit lines** can avoid unnecessary sprawling of sealed areas and increases urban connectivity leading to shorter transport distances with lower traffic emissions (IRP, 2018). Furthermore, spatial planning offers exactly the right moment and opportunity to **manage regional material flows in closed-cycle i**n the future. By integrating circular economy principles early in the urban development process, planners can lay the foundation for future urban mining and ensure that the infrastructure are conducive to the efficient and effective reuse, collection, and redistribution of resources (Ellen MacArthur Foundation, 2019a). A recently published study concluded that implementation of such circular economy measures for urban density changes may reduce urban areas by 14 million hectares globally (Forslund et al., 2022).

4.3 Fashion

The global textile industry, with its many interconnected global and local value chains, has now emerged as a major consumer of finite natural resources and have several serious impacts on the environment and biodiversity, in particular through land-use, pollution and waste management (Putt del Pino et al., 2017). Indeed, less than 1% of material used to produce clothing is recycled into new clothing, while 87% of the total fiber input used for clothing is either landfilled or incinerated (Ellen MacArthur Foundation, 2017). At the European level, even in countries with thriving collection practices (e.g. charities and private textile collectors and traders), much of the reusable clothing and most non-reusable clothing still ends up in mixed waste and represents a loss of valuable resources (ETC/WMGE, 2019; Köhler et al., 2021).
As described in chapter 2, the conventional textile industry has a negative impact on biodiversity along the whole life-cycle – from production of fibres to end of life. The supply chain of textiles is the fourth highest pressure category for use of primary raw materials and water, the second highest for land use and the fifth highest for greenhouse gas emissions (ETC/CE, 2022). In this context, it is important to note that over 90 % of the water and land used for producing textiles consumed in Europe occurs outside Europe, and thus also a responsibility for global biodiversity conservation arises (EEA, 2022f).

Within the textile industry, especially the clothing industry, there are many opportunities to minimise the negative effects on biodiversity with Circular Economy approaches in all phases of the value chain. In addition, especially where natural fibres are used, there is great potential to actively contribute to the regeneration of biodiversity through biodiversity-friendly sourcing measures.

Overconsumption

Especially the trend known as fast fashion, enticing consumers to keep on buying clothing of inferior quality and lower price, produced rapidly in response to the latest fashion trends, contribute the most to unsustainable patterns of overproduction and overconsumption in the textile industry. The overconsumption, especially of non-repairable and non-recyclable textiles, causes the need for cultivation of fibres, causing land use, extraction of water, use of fertilisers and pesticides and energy. Therefore, one of the most important factors for reducing biodiversity loss, is to reduce the production of new textiles. On the consumer side, the trend towards fast fashion must be addressed, above all, with measures for sustainable and conscious consumption. As changing consumer behaviour is difficult, different circular business models for changing the use of textiles have been developed (ETC/WMGE, 2019). According to Ellen MacArthur Foundation (2021a), there are four main business models for circulating products (and textiles):

1) **Rental:** this includes different leasing and rental opportunities between business to business and business to consumer. This can also be a part of 'user oriented' services in product-service-systems (PSS), where user can share and lease products (see example MUD Jeans).
2) **Resale:** includes resale of second-hand items both online and offline. This can be done by consumers them self (e.g., flea markets, online resale platforms) or by businesses, both the brand themselves and third-party businesses (e.g., resale on the brands website, resale through second-hand stores).
3) **Repair:** the operation by which a broken product is repaired. This can be done by consumers themselves or through repair facilities of the brand owners or third-party businesses.
4) **Remake:** the process of which a product is created from existing products, and by that remaking something discarded into a new product. This can be done both by consumers, brand-owners and third-party businesses.

Box 13: MUD Jeans

MUD Jeans – leasing a Jeans as business model
Founded: 2012
Origin: The Netherlands
CE framework: Reduce resource use, prevent waste and pollution

MUD Jeans sell and rent out jeans. They have built a business model where 40% of their costumers lease jeans for a monthly price of EURO 9,95, and after 12 months the costumer has the full ownership of the jeans. According to MUD, this encourages more people to repair and recycle their clothes.

Biodiversity benefit
In the last four years MUD have had a significant environmental impact, also contributing to biodiversity:

- 533 million litres of water saved
- 1 million kilos of CO2 avioded
- 160.000 m2a of land preserved

Source: www.mudjeans.eu

On the producer side, the main task is to implement a circular product design enabling long lasting products without harmful chemicals, that can be repaired or recycled (ETC/CE, 2022). According to the Ellen MacArthur Foundation (2021a), circular design considers the following points

1) **Physical durability:** material choices and garment constructions, to ensure highly durable products.
2) **Emotional durability:** applying strategies that increase and maintain a product's relevance and desirability over time.
3) **Remake and recyclability:** design for disassembly, and ensuring that all components can be repair, remaked or recycled into new products.

By extending the life of clothes with nine months, it has been estimated that one can safe between 20 and 30 % of the water and waste footprint (Cooper et al., 2013). This can be done by using circular design, but also encouraging repair and recycling through repair facilities and take-back systems as a new business model (ETC/CE, 2022). With the new Textile Strategy (European Commission, 2022b), the EU targets to reduce the textile industries environmental impact by extending the life of textile products including promoting repairable and recyclable textiles, design criteria, harmonised EU-legislation on extended producer responsibility and ending over consumption.

Biodiversity-friendly sourcing and recycling

In a biodiversity perspective, the production phase is one of the most polluting phases – both the production of fibres and manufacturing of textile products. A variety of design and production processes can be implemented, to ensure greater circularity in the production of fibres and products.
As stated in chapter 2, the production of fibre has a major negative impact on biodiversity. Shifting to sustainable, ideally regenerative fibre production can have a positive impact on the pollution connected to conventional fibre production and may foster biodiversity regeneration. An example of this is organic production of cotton, to decrease water and pesticide use, which has a positive impact on water resources and local pollution. But, the production of organic cotton only ensures the fibre production, and not the (potential harmful) chemicals added in the production of the textile product (ETC/WMGE, 2019). Furthermore, organic cotton production includes a high amount of land use (ETC/WMGE, 2019). As the main environmental impact of synthetic fibre is energy use, the recycling of these materials will have a major influence on the overall environmental impact (ETC/WMGE, 2019). To recycle fibres from clothing and household textile can reduce greenhouse gas emissions by 8 % (OVAM, 2019) and therefore reduce the climate change induced pressure on biodiversity.

Box 14: Lopyanko

Lopyanko: Circular Economy Silk Processing
Founded: 2013
Origin: Bulgaria
CE framework: reduce resource use, regenerate

Lopyanko developed with its AGRY_GAYA'18 project a so-called silk biorefinery. In addition to the production of raw silk, Lopyanko also produces various high-value products using the by-products and waste products of the silk production. The silkworm pupae are processed into protein powder, which is sometimes made into a high-quality food supplement, but is mostly used in the production of animal feed. In addition, sericin is extracted as a by-product of silk production.
The mulberry leaves used in the silkworm breeding are obtained in an ecologically high-quality agroforestry system. The mulberry trees are pruned, the leaves are fed to the Silkworms and the remaining branches are processed into pellets. the unconsumed leaves along with Silkworm litter and fecal matter are turned into compost that can be used on the Mulberry plantation.

Biodiversity benefit:
The production of food substrate in agroforestry systems increases biodiversity in the landscape and improves the microclimate. In addition, cultivated areas can regenerate. The closing of loops in the production process as far as possible and the high-quality processing of by-products and waste products also reduce the demand for raw materials in different sectors and the associated biodiversity effects.

Source: http://lopyanko.eu/

Although the collection of used clothing is established in many European countries, only a small proportion is actually reused, e.g. in second-hand shops or recycled to a high standard. A large part is rather used in downcycling processes (such as cleaning rags or vehicle interior linings) or energetically used. Therefore, improving recycling technologies, especially the development and scale-up of garment-to-yarn/yarn-to-yarn recycling technologies, is a major factor in looping fibres back into the system (Ellen MacArthur Foundation, 2017). These processes can be assisted by both designing out chemicals and producing textiles without mixed fibres, which will also have a major effect on the environmental impact through less pollution. Furthermore, different supporting technologies must be further developed, such as collecting, sorting and recycling (ETC/WMGE, 2019).

Box 15: Renewcell

Renewcell – recycling technologies for fibres
Founded: 2012
Origin: Sweden
CE framework: reduce resource use, prevent waste and pollution

Renewcell's recycling technology dissolves cellulose fibres like cotton from discarded garments and transforms them into Circulose® pulp, which can be used to make viscose, lyocell or other types of cellulosic fibres. In order to scale up and expand their impact, Renewcell is developing partnerships with key players in the fashion industry like H&M Group and viscose manufacturer Tangshan Sanyo.

Biodiversity benefit
By recycling fibres it reduces demand for virgin raw materials. Compared to producing fibres from virgin cotton or forestry products, Renewcell states that its fibre production process saves large amounts of water, manages chemicals in a closed-loop, zero-leakage environment, requires zero land for fibre cultivation, and stores rather than emits CO_2 by using 100 % renewable energy.

Source: https://www.renewcell.com/en/

4.4 Energy

An important part of the circular transition is also the use renewable energy sources (Kirchherr et al., 2017), as these decouple economic activities from the consumption of finite resources. A question that continues to be debated is whether or not energy recovery and incineration is part of the Circular Economy. On the one hand, this is seen in frameworks as the lowest and last stage (e.g. R9 in Potting et al., 2017), on the other hand as outside the scope with a need for minimisation through Circular Economy (e.g. Giurco et al., 2014, p. 436; EEA, 2019b). However, as stated in chapter 2, energy production and consumption can have a negative impact on biodiversity (Gasparatos et al., 2017). This is perhaps most apparent for bioenergy (and biofuel).

Clean energy technologies are becoming the fastest-growing segment of demand for critical minerals. Large-scale mining activities will put considerable strain on natural habitats via land use changes (or sea use changes in the case of deep-sea mining), infrastructure development, and environmental contamination. Land-use of both mining the minerals for renewable energy technology and the use of land in the production of energy can have an impact on biodiversity. Especially solar, hydropower, and wind energy uses large amount of land (Ritchie, 2022).

Product design and recycling

To reduce the impact of land use when mining new minerals for the manufacturing of especially solar panels and windmills, the circular economy can be a major driver for change. Circular design can reduce demand of new minerals, as materials can be reused and/or recycled to a higher degree.

To close the resource loop and reduces the impact on biodiversity, more innovative product designs are required that allow for the effective separation of constituent components and materials (Bennun et al., 2021). Wind turbines are a case in point in that regard. While most turbine components can be reused or recycled, most rotor blades are landfilled or burned as the use of highly durable composite materials makes it an arduous task to break them down to their constituent parts (Hellwig, 2022). Other renewable energy sources and components causes emerging waste streams, such as photovoltaics and energy storage systems (Graulich et al., 2021). To reduce the continuously need for new critical minerals and waste pollution, circular economy principles can reduce these challenges. As described in the box below, Ørsted (Box 16) is one energy company wanting to reuse, recycle or recover wind turbine blades.

Box 16: Orsted

Ørsted: Reuse, recycle, or recover wind turbines
Founded: 1972 (change name to Ørsted in 2017)
Origin: Denmark
CE framework: prevent waste and pollution

In 2021, Ørsted announced its commitment to either reuse, recycle, or recover all its wind turbine blades upon decommissioning. To help achieve its commitments the company aims to advance technologies (together with partners) that can recycle wind turbine blades in a sustainable way.
Ørsted is a founding member of the DecomBlades consortium, which seeks to investigate and develop solutions to recycle the composite material in wind turbine blades.

Biodiversity benefit:
Recycle wind blades reduces demand for raw materials (and energy), and reduces the need for landfills where many of the decommissioned blades end up. Both help lowers pressure on biodiversity.

Sources:
https://insights.issgovernance.com/posts/the-circular-economy-a-boon-for-biodiversity-conservation/
https://orsted.com/en/media/newsroom/news/2021/06/702084352457649

Biodiversity-friendly sourcing

While the need for primary raw materials can be minimised through Circular Economy measures, especially circular design, reuse and recycling, there is still a need to use a certain proportion of primary raw materials for the construction and operation of the energy system, among other things. Here, sustainable sourcing of primary raw materials must be ensured in accordance with EU principles (EC, 2021c). The mining industry has also recognised this and has included the impact of mining activities on biodiversity in its mining principles (SveMin, 2020; ICMM, 2022).

Bioenergy and the extraction of the necessary feedstocks play a special role with regard to biodiversity, as the fast-growing demand for bioenergy and biofuels risks outstripping sustainable supply of biomass (Material Economics et al., 2021). Therefore, to reduce the pressure on biomass supply and consequently also on biodiversity, biomass used for material should be prioritised above energy and only be used energetically at the end of a use cascade. The EU Commission is already addressing the effects associated with bioenergy with various strategies and regulations (see e.g. Best et al., 2021, Chapter 6). However, the discussion about the importance and effects of bioenergy remains complex and controversial, and is outside the scope of this report, which at this point focuses on the contribution of the circular economy to the sustainable provision of bioenergy. Here, regenerative production practices are of high importance.

According to Núñez-Regueiro et al. (2021), some of the potential impact of bioenergy crops on biodiversity can be overcome by recycling residue biomass or by converting intensive agriculture land with second generation bio crops. By doing so, closing nutrient cycles and improving degraded areas can also make a positive contribution to the regeneration of biodiversity. Bioenergy, obtained through the use of e.g. biowaste, by-products or residues that cannot be recycled, can be seen as a part of the biological cycle of circular economy, if the nutrients from the feedstock are recycled back to soil from either composting or anaerobic digestion and the resulted biogas is energetically used (Ellen MacArthur Foundation, 2019b).

Besides using residue biomass from agriculture or by-products e.g. from saw mills or paper industry, circular economy has also begun to focus on the need for recycling important nutrients from urban areas back to the soil. In these scenarios, technologies as biogas facilities and pyrolysis are being used to produce energy and recycle important nutrients back to the soil (Li and Feng, 2018). The nutrient balance from farmland to urban areas are in imbalance, as during the urbanisation, food is produced in farmland and consumed in urban areas. The nutrients from sewage sludge and organic waste (such as phosphorous), are not returned to farmland. By implementing circular principles in the energy and biological waste system, these nutrients can be recycled. This can also have a positive impact on the use of fertiliser and manure in agriculture. Thus, there are still challenges with recycling biogas sludge and circularity in wastewater treatment, as this can contain microplastic, fluorinated substances, and other residue from urban waste (EEA, 2022a; Mikkelsen and Ege, 2015).

Box 17: Genesis Biopartner

Genesis Biopartner
Founded: 2012
Origin: Romania
CE framework: reduce resource use, regenerate

Genesis Biopartner produce energy from organic waste and organic fertilizers. Roughly 60,000 tonnes of organic waste from retail (vegetables, fruit and bakery products, canteens and food industry per year, are fermented to gain biogas which is used to produce 2 MWh electric and 2 MWh thermal energy. At the end of the fermentation process the digestate is transferred into a nutrient-rich organic fertilizer.

Biodiversity benefit
When using biowaste instead of bio crop can reduce the biodiversity impacts associated the crop production. Furthermore, the use of fermentation digestate as fertilizer reduce the demand for artificial fertilizers and may close the nutrient cycle and reduce the nutrient imbalance between farmland and urban areas and therefore support the regeneration of agricultural soils.

Source: https://genesisbiopartner.ro/en/

4.6 Conclusions

This chapter investigates circular economy opportunities for reducing negative impacts on biodiversity in four value chains with significant negative impact on biodiversity loss (Kurth et al., 2021). These examples illustrate how negative impacts on biodiversity can be reduced through circular innovations and ambitious implementation of the circular economy policies and measures. It demonstrates how circular economy actions can reduce the need for raw materials, whether through measures for reuse, secondary raw material uses and recycling or through a more efficient use and extended life of products, can have a positive impact on reducing biodiversity losses.

Often, these opportunities (in most cases) provide synergies with climate mitigation by reducing virgin material and energy demand and consequently also greenhouse gas emissions. Measures to reduce the demand for raw materials can positively influence several of the drivers of biodiversity loss. The consideration of the examples thus reflects very well the findings from the overarching analysis of the interactions of the circular economy and biodiversity loss (Chapter 3). Furthermore, the examples illustrate that circular design is critical to realize the reduction of resource demand unique and actively contribute to the regeneration of biodiversity. The chapter also demonstrates that in addition to many innovative technical solutions, changing our consumption patterns towards a more sufficient use of products, and the way we use land is also crucial.

These examples represent a small selection of how circular economy actions can be utilised to reduce the impact our consumption and production patterns on biodiversity. In addition to foster these and many other examples we also need to consider systemic approach that unites the many opportunities out there from innovative design to consumption patterns and nature-based solutions.

5 Course of actions towards more biodiversity through a more circular economy in Europe

It has become increasingly clear that the extraction and cultivation of raw materials, especially in agriculture and forestry, is a major contributor to biodiversity loss. Subsequent steps along the value chain namely production, consumption, and disposal of waste also have a significant negative impact on the state of biodiversity. Consequently, the entire production and consumption system must be considered in order to reduce pressures on biodiversity. In this context, we analysed in chapter 2 the main drivers of biodiversity loss in Europe, evaluate the impacts of our current production and consumption and identified the domains with the greatest impact on biodiversity.

Leading scientific organisations (Pörtner et al., 2021; IPBES, 2019) have concluded that a transformative change of our consumption and production system is a central pillar to halt and reverse biodiversity loss (as well as other planetary crisis of climate change pollution). This is reflected in the EU Green Deal as well as recent international policy declarations (Leader's Pledge for Nature, 2020; UNEP, 2022). Circular economy aims to transform our economy from the current mostly linear take-make-waste model towards a closed-loop model. Circular economy represents a key engine for transforming our production and consumption system, and may thus also reduce negative impacts on biodiversity. To do so, biodiversity needs to play a more prominent part of circular economy. In response, the aim of this report is to evaluate how circular economy measures can contribute to reducing the pressure on biodiversity from production and consumption and, ideally, contribute to not only halting but also reversing biodiversity loss (see chapter 3 and chapter 4).

A framework for a more biodiversity-inclusive circular economy

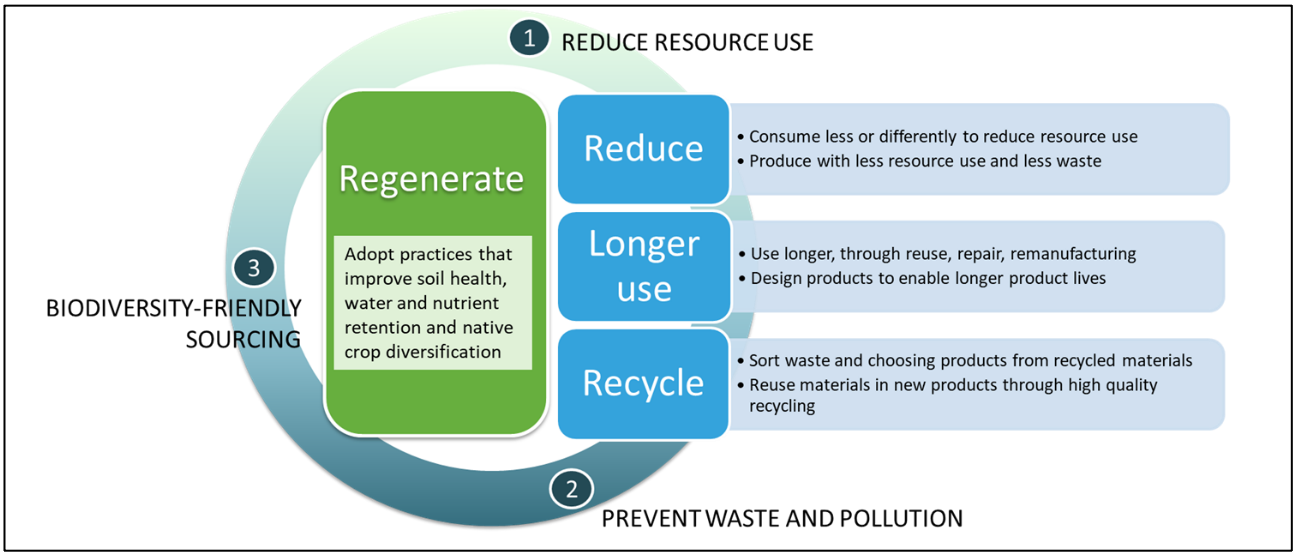
Circular economy measures can contribute to reducing biodiversity loss by reducing resource use (in consumption and production) and lowering demand for new materials. However, this needs to be combined with biodiversity-friendly sourcing of raw materials (and the prevention of waste and pollution at all stages of the value chain). Hence, to further development circular economy biodiversity protection and biodiversity-friendly sourcing considerations need to be factored in, e.g. nutrient retention, soil conservation, water management and sustainable pest management. This has the potential to not only reduce negative impacts for biodiversity, but also enable positive impacts through regenerative practices (Forslund et al., 2022). A biodiversity-inclusive circular economy needs to reduce demand for raw materials, avoid waste and emissions, and enhance regenerative processes at all stages of the product value chain when possible, especially in production processes related to agriculture, aquaculture and forestry (Kurth et al., 2021).

Nevertheless, it is precisely this aspect of regenerative and biodiversity-friendly sourcing, including conservation and restoration, practices that are somewhat neglected in current understandings of the circular economy. For this reason, we propose an adapted circular economy framework, which integrates regeneration as an underlying principle: the biodiversity-inclusive circular economy, with 3 core principles: (1) Reduce resource use, (2) Prevent waste and pollution; and (3) Biodiversity-friendly sourcing. This can be linked to the R-frameworks by adding a fourth underlying boundary condition 'Regenerate' to the traditional hierarchy of 'Reduce', 'Longer use' and 'Recycle' so the bio-economy is explicitly considered (Figure 5-8 A framework for a biodiversity-inclusive circular economyFigure 5-8).

Circular design: supporting longer product life

Although a variety of circular strategies each have their role to play in the different stages of the value chain, it is clear from the examples in the previous sections that product design is a key enabler for a biodiversity-inclusive circular economy. The way a product is designed is an important determinant for its environmental impacts. Material and assembly choices made during the product design stage will greatly influence a product's functionality, durability, repairability and recyclability, and thus the potential circular strategies and associated business models that can be deployed to optimise resource use, to extend a product's lifetime, or to disassemble the product and reuse or recycle its parts and materials at end of life (EEA, 2022f; ETC/CE, 2022). By choosing low-impact materials and developing designs that are durable, repairable and recyclable, the impact of products can be reduced, and waste can be avoided.

Figure 5-8 A framework for a biodiversity-inclusive circular economy



Source: ETC/CE (EEA, 2022; ETC/CE, 2022)

However, no comprehensive approach to promote eco-design is currently available at EU level, as it mainly relies on sectoral legislation (EU, 2009) and voluntary tools (EU ecolabel and green public procurement). The 2020 CEAP planned, therefore, a sustainable product policy legislative initiative, to ensure that all products placed on the EU market become increasingly sustainable and stand the test of circularity. This will also result in the minimisation of waste and pollution (EC, 2021a). The new proposed Regulation (EC, 2022a) widens the scope of the Eco-design Directive (EU, 2009) beyond energy-related products and, through EC delegated acts, will introduce eco-design requirements for products not already (adequately) covered by the EU legislation. Priority will be given to products identified by the 2020 CEAP (electronics, ICT and textiles), but also to furniture and high impact intermediary products, such as steel, cement and chemicals. According to the Commission proposal, eco-design requirements should address key issues such as products durability, reusability, reparability; the presence of substances of concern; resource efficiency; recycled content; the possibility of recycling, etc. They include both performance and information requirements. The proposed Regulation also shapes a general obligation of transparency for economic operators (excluding SMEs) who discard unsold consumer products and provides for the possible setting, via EC delegated acts, of green public procurement (GPP) requirements applicable to public contracts.

The transition towards safer materials and products (which is a fundamental component of eco-design) is also supported by the Chemicals Strategy for Sustainability (EC, 2020a), with a specific focus on product categories that affect vulnerable populations and on those with the highest potential for circularity (e.g. packaging, ICT, furniture, etc.). This will be achieved, inter alia, by moving to safe and sustainable-by-design chemicals, including sustainable bio-based chemicals.

A need for systemic solutions

Even if the Circular Economy is an approach for the above-mentioned necessary fundamental systemic change (Pörtner et al., 2021; IPBES, 2019; Ellen MacArthur Foundation, 2021b) it is challenging to tackle biodiversity loss drivers by dedicated actions, as actions targeting one particular driver will affect the other drivers as well, and potentially unintended negative consequences (Forslund, 2021). These include trade-offs that are difficult to settle. For example, substitution with renewable raw materials can lead to increase land use changes and shifts towards intensive monoculture, with negative effects on biodiversity. The transformation of our consumption and production system is a simple path but can lead to both solution and new challenges. While incremental changes are essential for their cataclysmic effects, a systemic perspective is indispensable in the implementation and further development of the circular economy in promoting, in order to leverage synergies between the circular economy climate protection and biodiversity conservation and reduce trade-offs.

Changing consumption

Circular economy's contribution to biodiversity is not only achieved through optimising production processes, sustainable consumption and the idea of 'sufficiency' needs to be considered. In this vein, measures that steer consumers towards a more sustainable direction, both in terms of products consumed and the overall levels of consumption, will be an essential complement to the more technical approaches of circular economy, thus minimizing the need and demand for new products. The difficult questions of how much and what we consume should come more to the forefront of circular economy. For example, one step that has recently been discussed again would be to set clear targets for the maximum use of primary raw materials, both abiotic and biomass (Bringezu, 2022; Dutch Government, 2019).

5.1 Options for better integrating circular economy and biodiversity protection

In order to achieve an ambitious implementation of the circular economy, three main levels need to be addressed. Policymakers and political actors need to create the necessary framework conditions for further integrating the circular economy and biodiversity. Companies including small and medium enterprises need to develop and scale-up circular innovations, not least during production and design stages. Consumers, through changes in demand patterns can trigger a pull-effect for the transformation of production and at the same time actively contribute to the success of the transformation through their behaviour.

Policy considerations

The EU has established an extensive legislative and policy framework on Circular Economy. The 2015 Circular Economy Action Plan (CEAP; EC, 2015) contributed significantly to the development of such a framework, which is currently further evolving based on the European Green Deal (EGD; European Commission, 2019) and the 2020 New Circular Economy Action Plan (European Commission, 2020a). An in-depth qualitative analysis of the interconnections between the EU circular economy (CE), biodiversity (BIO) and climate policy domains (DEC) has been carried out in the technical supporting material (ETC/CE, 2023), which investigates, in particular, whether and how circular economy policy and measures are expected to alleviate pressures on biodiversity (and on climate change). Building on this analysis and on the previous sections of the report, some remarks on the interconnections between the EU circular economy and biodiversity and climate policies are presented, as well as a number of suggestions on what circular economy policy approaches and tools may receive a priority to better protect and restore biodiversity and ecosystems.

At the policy level, circular economy has traditionally been conceived as a separate policy domain compared to biodiversity and climate change. With the EGD (European Commission, 2019), the Commission has made a significant effort to overcome the abovementioned 'silo approach', by shaping a comprehensive and integrated growth strategy to transform the EU into a climate neutral and resource efficient economy, while protecting, conserving and enhancing the EU's natural capital. The connection between circular economy and biodiversity is also recognised by the 2020 Circular Economy Action Plan (European Commission, 2020a), which states that 'more than 90 % of biodiversity loss and water stress come from resource extraction and processing' (p. 1) and that 'the circular economy can significantly reduce the negative impacts of resource extraction and use on the environment and contribute to restoring biodiversity and natural capital in Europe' (p. 12). Circular economy can not only alleviate pressure on biodiversity/ecosystems, but it also supports both climate adaptation and mitigation (GHG emissions reductions and removals), by transforming the way in which goods are produced and used. According to the EGD, circular economy is a prerequisite for climate neutrality and the 2020 CEAP shapes a set of specific actions that are aimed at enhancing synergies between circularity and climate mitigation.

In line with the EGD, in order to enhance synergies and manage trade-offs between CE-BIO-DEC policies, it is urgent to promote the transition from a 'silo' to a more 'integrated' approach in the design and implementation of EU environmental policies. Policy measures that are too narrowly focused on the achievement of specific objectives risk to produce unintended negative effects on the environment. The EU Taxonomy Regulation (EU, 2020), with its delegated acts, is a good example of an 'integrated policy framework'. The Regulation aims at providing clarity for companies, capital markets, and policy makers on which economic activities are sustainable, and includes six environmental objectives:

1. climate change mitigation,
2. climate change adaptation,
3. the sustainable use and protection of water and marine resources,
4. the transition to a circular economy,
5. pollution prevention and control,
6. the protection and restoration of biodiversity and ecosystems.

In order to be qualified as 'environmentally sustainable', an economic activity must provide a 'significant contribution' to at least one of the six environmental objectives and 'do no significant harm' to any of the other objectives, while respecting basic human rights and labour standards. The overall effect of the EU Taxonomy Regulation will depend on the selection of technical screening criteria for each of the environmental objectives (still to be adopted). 'Criteria should ensure that activities that are somehow less harmful to biodiversity (better than a business-as-usual scenario), but not fully biodiversity-friendly are not defined as substantially contributing to the protection of biodiversity and ecosystems' (Schrems and Bär, 2021, p. 17).

The adverse side-effects generated by non-integrated environmental policy measures may be more pronounced in those policy areas, such as biodiversity, in which voluntary approaches predominate. Therefore, along with the promotion of an 'integrated policy approach', it will be essential to adopt a binding legal framework on nature and soil, as planned by the 2030 EU Biodiversity Strategy (EC, 2020b) and the EU Soil Strategy (EC, 2021b)

In particular, the proposed Regulation on nature restoration (EC, 2022b) sets multiple binding restoration targets and obligations across a broad range of ecosystems (urban, agriculture, forests, marine, rivers ecosystems, etc.). These measures should cover at least 20 % of the EU's land and sea areas by 2030 and all ecosystems in need of restoration by 2050. Biodiversity policy could also be strengthened by the introduction of market-based instruments (already widely applied in the CE and DEC policy domains) that send price signals and provide incentives for sustainable behaviour by producers, users, and consumers. With this regard, the 2030 BDS (EC, 2020b) argues that the Commission will 'promote tax systems and pricing that reflect environmental costs, including biodiversity loss', but no specific measures have been scheduled so far.

Regeneration is mentioned by the 2020 CEAP ('regenerative growth model that gives back to the planet more than it takes'), yet the sustainability of resource extraction still needs to become a full component of the circular economy concept and to be supported through adequate circular economy measures. This should apply, in the first place, to circular economy measures addressing the value chains with the highest pressure on biodiversity in Europe, e.g. agriculture. Yet the objective of 'sustainable extraction' may apply to the whole economy including to products imported into the EU (Kettunen et al., 2020). For instance, a new Regulation has been proposed by the European Commission to minimise EU-driven deforestation and forest degradation, by promoting the consumption of 'deforestation-free' products (EC, 2021d).

5.2 The role of business

Driven by the increasing awareness on biodiversity loss and leaning on their experience with consumer demands for more sustainable products and due to legal requirements for businesses to account for the environmental risks to their operation and reputation, companies are increasingly addressing the issue of biodiversity loss as a business risk. The World Economic Forum (2020) described biodiversity loss as a major systemic risk for our economy and evaluate how biodiversity loss and ecosystem degradation can create risks for business in particular:

- Dependency of business on nature: when businesses depend directly on nature for operations, supply chain performance, real estate asset values, physical security, and business continuity
- Fallout of business impacts on nature: when the direct and indirect impacts of business activities on nature loss trigger negative consequences, such as losing customers or entire markets, costly legal action, and adverse regulatory changes
- Impacts of nature loss on society: when nature loss aggravates the disruption of the society in which businesses operate, which in turn can create physical and market risks

Failing to integrate protection, restoration and sustainable use of biodiversity into business activities poses not only operational and financial risks, because conservation, sustainable use and restoration of biodiversity can provide significant business opportunities, reaching from cost savings and increased market shares to new business models, markets, products and services as well as a better relationship with stakeholders and customers (OECD, 2019). For this reason, already several business initiatives tackle the issue of biodiversity loss, for example: the EU Business @ Biodiversity Platform (EC, 2022c), the One Planet Business for Biodiversity coalition (WBCSD, 2019), a cross-sectorial initiative to help preserve and restore biodiversity in agriculture, and the Business for Nature initiative (Business for Nature, 2022), in which companies together with non-governmental organizations (NGOs) aim to influence policy-making and introduce nature to economic decision-making.

In recent years, a number of studies have looked at how biodiversity loss can be systematically addressed as a business risk (Kurth et al., 2021; OECD, 2019; Science-based targets Network, 2020; e.g. World Economic Forum, 2020b; López and Teufel, 2022). Following these studies, the first step is to determine the impact on biodiversity through the respective business model or the companies value chains and to derive the main fields of action from this. However, the recent published Nature Benchmark study (World Benchmarking Alliance, 2022) showed that just a minority of the analysed companies have carried out a science-based assessment looking at how their operations and business model have an impact on nature and biodiversity. Knowing the impact on biodiversity, priorities can be identified and science-based targets and a corresponding monitoring system can be established in a second step.
After that, it is important to establish the necessary conditions, both internally (e.g. through further training of employees) and externally (e.g. through appropriate cooperation and partnerships). As final step, the development and implementation of the right measures for the respective value chain with the aim to reduce the biodiversity footprint by transforming the value chains through innovative, biodiversity-positive products and services has to be carried out.

For this last step, e.g. the Science-based target network (2020) developed the so-called AR^{3}T framework setting actions in a priority order:

1. **Avoid**: Circular business models help to avoid negative impacts on biodiversity by recirculating existing products and decreasing the use of virgin materials.
2. **Reduce**: Increasing the recycled content of our products help reduce the impact on biodiversity associated with sourcing virgin materials.

3. **Restore & regenerate**: Regenerative agriculture and conservation projects help to restore natural habitats and increase the resilience of nature.
4. **Transform**: Through collaborating with others, we bring about transformation change to the fashion industry.

As can be seen, circular economy plays a decisive role in the framework. By identifying and adapting circular business models which can help reach the biodiversity targets, business also can influence how products and materials are produced, consumed and managed. Circular economy business frameworks, like the ReSOLVE framework (Ellen MacArthur Foundation and McKinsey Center for Business and Environment, 2015), can help companies to do so. Through the changeover to a circular design based on informed choices at the design and sourcing stages, companies can consistently reduce the main drivers of biodiversity loss in their value chains and business models.

5.3 Sustainable consumption

As the previous chapters have shown, addressing our consumption levels and choices are key to reduce the current overconsumption of natural resources and its respective biodiversity impacts. Especially. land use is heavily impacted, e.g. by our dietary choices, and therefore a crucial part of protecting our biodiversity and ecosystems (Sun et al., 2022). In addition, a one-to-one substitution e.g. of minerals or fossil energy carriers by biomass use is not viable as between the projected demand and available supply of biomass in the EU by 2050 a 40-70 % gap can be expected (Material Economics et al., 2021). It is thus clear that business as usual consumption cannot continue as before if planetary boundaries are not to be exceeded and biodiversity loss should be stopped. Since the negative effects of our consumption, especially of biomass production and use, on biodiversity are already clearly visible today, it becomes clear that it is not enough to close the existing material cycles as far as possible. Rather, it is important to recognise that the size of the material cycles is also relevant and must be brought to an environmentally compatible and sustainable level (Bringezu, 2022; IRP, 2019; Desing et al., 2020). The fact that sustainable consumption is part of the Circular Economy concepts and can contribute to reducing overconsumption and therefore biodiversity loss with approaches such as reduced consumption, longer product use or increased demand for sustainable products has already been shown in Chapter 3.

With regard to food consumption, which is particularly relevant for biodiversity protection, it can be stated that the two largest adjustment screws are a shift to plant-rich diets with less red meat and dairy as well as the reduction of food waste (UNEP and One Earth, 2018; Benton et al., 2021). In addition, consumers can support biodiversity-promoting and environmentally friendly food production through their product choices, e.g. for organically grown food or regional and seasonal fruit and vegetables.

As efficiency and consistency might not be sufficient to achieve the necessary reduction of the material cycles, sufficiency should be increasingly considered as a third strategy. According to the IPCC (2022, p. SPM-41) “sufficiency policies are a set of measures and daily practices that avoid demand for energy, materials, land and water while delivering human wellbeing for all within planetary boundaries”.

Especially the relevant consumer sectors of construction and housing as well as clothing offer potential here. E.g, ‘slow fashion’ is proposing an alternative to the current trend of ´fast fashion, trying to convince consumers to buy fewer clothes, made of high-quality durable materials and long-lasting styles. This can also include extending the lifetime of clothes, e.g. through mending, upcycling, second-hand use or clothes swapping (UNEP and One Earth, 2018). Reducing the area needed for buildings through smaller dwellings, reduced living space per person, co-working and co-living spaces will have positive effects on biodiversity and climate mitigation ((IPCC, 2022; UNEP and One Earth, 2018).

5.4 Conclusions

As elaborated in the present report, our production and consumption system needs to be transformed to reduce pressure on biodiversity. Circular Economy can be seen as one transformation strategy addressing the way we produce and consume goods and services and offer a unique opportunity to support biodiversity protection and, depending on the sector, also to regenerate biodiversity. However, this requires biodiversity to be considered to a greater extent in the design and implementation of the Circular Economy.

The biodiversity-inclusive circular economy framework, developed in this report, reflect on three core principles (i) reduce resource use, (ii) prevent waste and pollution and (iii) biodiversity-friendly sourcing. In implementing such a framework, Circular (eco-)design can be a key enabler. The way a product is designed is an important determinant for its environmental impacts. By choosing low-impact materials and developing designs that are durable, repairable and recyclable, the impact of products can be reduced and waste can be avoided.

Furthermore, systemic approaches are also crucial. It can be challenging to tackle individual drivers of biodiversity loss, as actions targeting one driver may negatively affect other drivers. These trade offs can be difficult to settle. For this reason, a systemic perspective is indispensable in the implementation and further development of the circular economy, in order to best leverage the existing synergies between the circular economy, climate protection and biodiversity conservation while minimise trade-offs.

Technical innovations and Changing consumption patterns will be essential. Finding innovate solutions and scaling them up are of particular relevance, especially when it comes to regenerative practices. Here the scalability is sometimes questioned. There are several local examples where regenerative practices have been achieved (at least partially). Here innovations and 'thinking out of the box' is needed, coupled with changes in policy framework (factoring in ecosystem services into the economy) and changes to consumption patterns. The question of how much and what we consume should come more to the forefront. Dietary shifts can in themselves free-up a significant amount of anthropogenic land and water use, as well as greenhouse gas emissions. The difficult issues of overconsumption and sufficiency will need to be addressed as an essential complement to the more technical approaches of circular economy, in order to reduce the negative impacts of our consumption and production system sufficiently to allow biodiversity and ecosystems to regenerate.

Incorporate various stakeholders, policymakers and political actors are needed to create the necessary framework conditions and to ensure the required systemic perspective in implementation and further development. Companies (large and small) are needed to implement the transformation of production and a more circular perspective in product design and use. Finally, consumers and consumer demands can help pull the transformation of production and at the same time actively contribute to the success of the transformation through their consumer behaviour.

Despite the many approaches and possibilities offered by a biodiversity-inclusive circular economy, it should be noted that Circular Economy should not be seen as a panacea as it has clear limits in addressing biodiversity loss and policies and measures specifically designed for biodiversity protection remain indispensable.

References

Alexander, T. J., et al., 2017, 'Does eutrophication-driven evolution change aquatic ecosystems?', *Philosophical Transactions of the Royal Society B: Biological Sciences* 372(1712), p. 20160041 (DOI: 10.1098/rstb.2016.0041).

Altieri, M. A., 1999, 'The ecological role of biodiversity in agroecosystems', , p. 13.

Angel, B., et al., 2022, 'Tackling the textile industry's carbon footprint' (https://www.woodmac.com/news/opinion/tackling-the-textile-industrys-carbon-footprint/) accessed 15 December 2022.

Babí Almenar, J., et al., 2019, 'Assessing habitat loss, fragmentation and ecological connectivity in Luxembourg to support spatial planning', *Landscape and Urban Planning* 189, pp. 335-351 (DOI: 10.1016/j.landurbplan.2019.05.004).

Badia, A., et al., 2011, 'Identifying dynamics of fire ignition probabilities in two representative Mediterranean wildland-urban interface areas', *Applied Geography* 31(3), pp. 930-940 (DOI: 10.1016/j.apgeog.2011.01.016).

Bakker, C. A., et al., 2014, 'Products that go round: Exploring product life extension through design', *Journal of Cleaner Production* 69, pp. 10-16 (DOI: 10.1016/j.jclepro.2014.01.028).

Ben-Hamadou, R., 2017, 'Algae biorefinery — promise and potential', EcoMENA (https://www.ecomena.org/algae-biorefinery/) accessed 17 October 2017.

Benítez-López, A., et al., 2010, 'The impacts of roads and other infrastructure on mammal and bird populations: A meta-analysis', *Biological Conservation* 143(6), pp. 1307-1316 (DOI: 10.1016/j.biocon.2010.02.009).

Bennun, L., et al., 2021, *Mitigating biodiversity impacts associated with solar and wind energy development: guidelines for project developers*, IUCN, International Union for Conservation of Nature.

Benton, T. G., et al., 2021, *Food system impacts on biodiversity loss*, Chatham House, London (https://www.chathamhouse.org/sites/default/files/2021-02/2021-02-03-food-system-biodiversity-loss-benton-et-al_0.pdf) accessed 4 February 2022.

Best, A., et al., 2021, 'Assessment of resource nexus-related challenges and opportunities in the context of the European Green Deal. Background report for the EEA Briefing "Applying a "resource nexus" lens to policy: opportunities for increasing coherence', , p. 91.

Bjerregaard, R., et al., 2016, *Seaweed aquaculture for food security, income generation and environmental health in Tropical Developing Countries*, World Bank Group, Washington D.C. (http://documents.worldbank.org/curated/en/947831469090666344/Seaweed-aquaculture-for-food-security-income-generation-and-environmental-health-in-Tropical-Developing-Countries).

Bocken, N. M. P., et al., 2016, 'Product design and business model strategies for a circular economy', *Journal of Industrial and Production Engineering* 33(5), pp. 308-320 (DOI: 10.1080/21681015.2016.1172124).

Boucher, J. and Friot, D., 2017, *Primary microplastics in the oceans: a global evaluation of sources*, IUCN, Gland, Switzerland (https://www.iucn.org/content/primary-microplastics-oceans) accessed 2 March 2020.

Bringezu, S., 2022, *The World Budget: Safe and fair resource use for global survival and well-being*,.

Buchmann-Duck, J. and Beazley, K. F., 2020, 'An urgent call for circular economy advocates to acknowledge its limitations in conserving biodiversity', *Science of The Total Environment* 727, p. 138602 (DOI: https://doi.org/10.1016/j.scitotenv.2020.138602).

Business for Nature, 2022, 'About Business for Nature', Business For Nature (https://www.businessfornature.org/about) accessed 16 December 2022.

BusinessEurope, 2019, 'Gugler*: a company devoted to circular economy and sustainability', Circulary (http://www.circulary.eu/project/gugler/) accessed 6 December 2022.

Calheiros, C. S. C. and Stefanakis, A. I., 2021, 'Green Roofs Towards Circular and Resilient Cities', *Circular Economy and Sustainability* 1(1), pp. 395-411 (DOI: 10.1007/s43615-021-00033-0).

Carbon Trust, 2011, *International Carbon Flows - Clothing*, International Carbon Flows, Carbon Trust (https://ctprodstorageaccountp.blob.core.windows.net/prod-drupal-files/documents/resource/public/International%20Carbon%20Flows%20-%20Clothing%20-%20REPORT.pdf) accessed 19 December 2022.

Carmichael, A., 2015, 'Man-Made Fibers Continue To Grow', Textile World (https://www.textileworld.com/textile-world/fiber-world/2015/02/man-made-fibers-continue-to-grow/) accessed 19 December 2022.

Chazdon, R. L. and Guariguata, M. R., 2016, 'Natural regeneration as a tool for large-scale forest restoration in the tropics: prospects and challenges', CIFOR (https://www.cifor.org/knowledge/publication/6282/) accessed 12 April 2022.

Chislock, M. F., et al., 2013, 'Eutrophication: Causes, Consequences, and Controls in Aquatic Ecosystems', *Nature Education Knowledge* 4(4), p. 10.

Churkina, G., et al., 2020, 'Buildings as a global carbon sink', *Nature Sustainability* 3(4), pp. 269-276 (DOI: 10.1038/s41893-019-0462-4).

Convention on Biological Diversity, 2022, Kunming-Montreal Global biodiversity framework (CBD/COP/15/L.25), (https://www.cbd.int/doc/c/e6d3/cd1d/daf663719a03902a9b116c34/cop-15-l-25-en.pdf).

Cooper, T., et al., 2013, *Design for longevity: guidance on increasing the active life of clothing: report for WRAP*, WRAP (Waste & Resources Action Programme).

Copernicus, 2022, *European state of the climate 2022* (https://climate.copernicus.eu/esotc/2022).

d'Amato, D. and Korhonen, J., 2021, 'Integrating the green economy, circular economy and bioeconomy in a strategic sustainability framework | Elsevier Enhanced Reader', *Ecological Economics* 188, p. 107143 (DOI: https://doi.org/10.1016/j.ecolecon.2021.107143).

Davis, T., 2003, *Agricultural water use and river basin conservation*, WWF (World Wide Fund for Nature), Gland, Switzerland (https://wwfeu.awsassets.panda.org/downloads/agwaterusefinalreport.pdf) accessed 19 December 2022.

Debacker, W. and Manshoven, S., 2016, *Key barriers and opportunities for Materials Passports and Reversible Building Design in the current system*, No D1 Synthesis of the state-ofthe-art (https://www.bamb2020.eu/wp-content/uploads/2016/03/D1_Synthesis-report-on-State-of-the-art_20161129_FINAL.pdf) accessed 6 December 2022.

Delpero, C., 2022, ‘POPs: Deal reached on limits of harmful “forever chemicals” in waste’, ENDS Europe (https://www.endseurope.com/article/1790637?utm_source=website&utm_medium=social) accessed 20 September 2022.

Derisi, S., 2016, ‘The Dirty Side of the Garment Industry: Fast Fashion and Its Negative Impact on Environment and Society’ Anguelov, N. (ed.), *Modern Language Studies* 46(1), pp. 87-89.

Desing, H., et al., 2020, ‘A circular economy within the planetary boundaries: Towards a resource-based, systemic approach’, *Resources, Conservation and Recycling* 155, p. 104673 (DOI: 10.1016/j.resconrec.2019.104673).

Dutch Government, 2019, ‘Circular Dutch economy by 2050’ (https://www.government.nl/topics/circular-economy/circular-dutch-economy-by-2050) accessed 9 December 2022.

EC, 2015, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, ‘Closing the loop — an EU action plan for the circular economy’ (COM(2015) 614 final).

EC, 2020a, Communication from the Commission to the European Parliament, the Council, the Economic and Social Committee and the Committee of the Regions ‘Chemicals strategy for sustainability. Towards a toxic-free environment’ (COM(2020) 667 final, Brussels, 14.10.2020).

EC, 2020b, Communication from the Commission to the European Parliament, the Council, the Economic and Social Committee and the Committee of the Regions ‘EU Biodiversity Strategy for 2030. Bringing nature back into our lives’ (COM(2020)380 final, Brussels, 20.5.2020).

EC, 2020c, *Farm to fork strategy: for a fair, healthy and environmentally-friendly food system*, European Commission (https://ec.europa.eu/food/system/files/2020-05/f2f_action-plan_2020_strategy-info_en.pdf) accessed 8 November 2021.

EC, 2021a, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: pathway to a healthy planet for all ‘EU action plan: towards zero pollution for air, water and soil’ (COM(2021) 400 final).

EC, 2021b, Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions ‘EU Soil Strategy for 2030 - Reaping the benefits of healthy soils for people, food, nature and climate’ (COM(2021)699).

EC, 2021c, *EU principles for sustainable raw materials.*, Publications Office, LU.

EC, 2021d, Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the making available on the Union market as well as export from the Union of certain commodities and products associated with deforestation and forest degradation and repealing Regulation (EU) No 995/2010 (COM(2021)706).

EC, 2022a, Proposal for a Regulation of the European Parliament and of the Council establishing a framework for setting ecodesign requirements for sustainable products and repealing Directive 2009/125/EC (COM(2022)142).

EC, 2022b, Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on nature restoration (COM(2022)304).

EC, 2022c, ‘The EU Business @ Biodiversity Platform | Home’ (https://ec.europa.eu/environment/biodiversity/business/index_en.htm) accessed 9 December 2022.

ECOS, 2021, *Durable, repairable and mainstream — how ecodesign can make our textiles circular*, ECOS (https://ecostandard.org/wp-content/uploads/2021/04/ECOS-REPORT-HOW-ECODESIGN-CAN-MAKE-OUR-TEXTILES-CIRCULAR.pdf) accessed 30 August 2021.

EEA, 1999, *Environmental indicators: typology and overview*, Technical Report No 25/1999, European Environment Agency (http://www.eea.europa.eu/publications/TEC25).

EEA, 2016, *Circular economy in Europe — Developing the knowledge base*, Publication No 2/2016 (https://www.eea.europa.eu/publications/circular-economy-in-europe) accessed 4 February 2022.

EEA, 2017, *Food in a green light: a systems approach to sustainable food*, EEA Report No 16/2017, European Environment Agency (https://www.eea.europa.eu/publications/food-in-a-green-light/at_download/file) accessed 12 October 2018.

EEA, 2018a, *European waters assessment of status and pressures 2018*, European Environment Agency, Luxembourg (https://www.eea.europa.eu/publications/state-of-water) accessed 8 June 2020.

EEA, 2018b, *The circular economy and the bioeconomy — Partners in sustainability — European Environment Agency*, Publication No 8/2018 (https://www.eea.europa.eu/publications/circular-economy-and-bioeconomy) accessed 29 March 2022.

EEA, 2019a, *Healthy environment, healthy lives: how the environment influences health and well-being in Europe*, EEA Report No 21/2019, Europe Environment Agency (https://www.eea.europa.eu/publications/healthy-environment-healthy-lives/download) accessed 16 December 2022.

EEA, 2019b, *The European environment — state and outlook 2020*, Publication, European Envionment Agency (EEA) (https://www.eea.europa.eu/publications/soer-2020) accessed 8 July 2022.

EEA, 2019c, 'Water use and environmental pressures', European Environment Agency (https://www.eea.europa.eu/themes/water/european-waters/water-use-and-environmental-pressures/water-use-and-environmental-pressures#toc-0) accessed 14 March 2021.

EEA, et al., 2020, *Bellagio Declaration - Circular Economy Monitoring Principles* (https://epanet.eea.europa.eu/reports-letters/reports-and-letters/bellagio-declaration.pdf) accessed 8 July 2022.

EEA, 2020a, *Bio-waste in Europe — turning challenges into opportunities*, EEA report No 4/2020, European Environment Agency (https://www.eea.europa.eu/publications/bio-waste-in-europe) accessed 20 June 2020.

EEA, 2020b, 'Ecological footprint of European countries' (https://www.eea.europa.eu/data-and-maps/indicators/ecological-footprint-of-european-countries-2/assessment) accessed 15 December 2022.

EEA, 2020c, 'Impacts due to over-abstraction' (https://www.eea.europa.eu/archived/archived-content-water-topic/water-resources/impacts-due-to-over-abstraction) accessed 12 December 2022.

EEA, 2020d, *State of nature in the EU: results from reporting under the nature directives 2013-2018*, EEA Report No 10/2020, European Environment Agency (https://www.eea.europa.eu/publications/state-of-nature-in-the-eu-2020) accessed 4 December 2020.

EEA, 2021a, *A framework for enabling circular business models in Europe — European Environment Agency*, Briefing (https://www.eea.europa.eu/publications/a-framework-for-enabling-circular) accessed 1 December 2022.

EEA, 2021b, 'EEA greenhouse gases - data viewer — European Environment Agency' (https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer) accessed 15 December 2022.

EEA, 2022a, *Beyond water quality - Sewage treatment in a circular economy*, EEA Report No 05/2022, EEA, Copenhagen (https://www.eea.europa.eu/ds_resolveuid/6f3e68b2934340d594b22370ef8cfde2).

EEA, 2022b, 'Building renovation: where circular economy and climate meet', European Environment Agency (https://www.eea.europa.eu/publications/building-renovation-where-circular-economy) accessed 10 October 2022.

EEA, 2022c, 'Fragmentation', Biodiversity Information System for Europe (https://biodiversity.europa.eu/threats/fragmentation) accessed 15 December 2022.

EEA, 2022d, 'Landscape fragmentation pressure in Europe' (https://www.eea.europa.eu/ims/landscape-fragmentation-pressure-in-europe) accessed 15 December 2022.

EEA, 2022e, 'Oxygen consuming substances in European rivers' (https://www.eea.europa.eu/ims/oxygen-consuming-substances-in-european-rivers) accessed 12 December 2022.

EEA, 2022f, *Textiles and the environment: the role of design in Europe's circular economy*, Briefing, European Environment Agency (https://www.eea.europa.eu/publications/textiles-and-the-environment-the/textiles-and-the-environment-the) accessed 11 February 2022.

EEA, 2022g, *Zero pollution monitoring assessment*, EEA Web Report No 03/2022, European Environment Agency (https://www.eea.europa.eu/publications/zero-pollution) accessed 8 December 2022.

EEA, forthcoming, Biomass is at the centre of many environmental and climate policies in the European Union (EU) and is set to play a key role in the transition to a sustainable, climate-neutral economy.

Ellen MacArthur Foundation, 2017, *A new textiles economy: redesigning fashion's future*, Ellen MacArthur Foundation (https://emf.thirdlight.com/link/2axvc7eob8zx-za4ule/@/preview/1?o) accessed 21 January 2022.

Ellen MacArthur Foundation, 2019a, 'Factsheets — Circular economy in cities' (https://www.ellenmacarthurfoundation.org/our-work/activities/circular-economy-in-cities/factsheets) accessed 12 May 2021.

Ellen MacArthur Foundation, 2019b, 'The biological cycle of the butterfly diagram' (https://ellenmacarthurfoundation.org/articles/the-biological-cycle-of-the-butterfly-diagram) accessed 15 December 2022.

Ellen MacArthur Foundation, 2021a, *Circular Business Models: Redefining growth for a thriving fashion industry*, Ellen MacArthur Foundation (https://emf.thirdlight.com/link/circular-business-models-report/@/preview/1?o) accessed 10 December 2021.

Ellen MacArthur Foundation, 2021b, *The Nature Imperative: How the circular economy tackles biodiversity loss* (https://emf.thirdlight.com/link/bqgxl2mlprld-v7i2m6/@/preview/1?o) accessed 3 February 2022.

Ellen MacArthur Foundation, 2022, 'A building that can be reused: Brummen Town Hall' (https://ellenmacarthurfoundation.org/circular-examples/brummen-town-hall) accessed 6 December 2022.

Ellen MacArthur Foundation and McKinsey Center for Business and Environment, 2015, *Growth within: A circular economy vision for a competitive Europe*, Ellen Mac Arthur Foundation and McKinsey Center for

Business and Environment, Cowes, UK (https://www.ellenmacarthurfoundation.org/assets/downloads/publications/EllenMacArthurFoundation_Growth-Within_July15.pdf) accessed 12 April 2022.

ETC/CE, 2022, *Textiles and the environment - The role of design in Europe's circular economy*, Eionet Report No ETC/CE 2022/2 (https://www.eionet.europa.eu/etcs/etc-ce/products/etc-ce-products/etc-ce-report-2-2022-textiles-and-the-environment-the-role-of-design-in-europes-circular-economy) accessed 11 February 2022.

ETC/CE, 2023, *Policy framework analysis – Technical supporting material to the report "Circular Economy and Biodiversity"*, No ETC-CE 2023/7bis (https://www.eionet.europa.eu/etcs/etc-ce/products/etc-ce-report-2023-7-circular-economy-and-biodiversity).

ETC/WMGE, 2019, *Textiles and the environment in a circular economy*, Eionet Report No 6/2019, European Topic Centre for Waste and Materials in a Green Economy (https://www.eionet.europa.eu/etcs/etc-wmge/products/etc-reports/textiles-and-the-environment-in-a-circular-economy) accessed 26 March 2020.

ETC/WMGE, 2020, *Construction and Demolition Waste: challenges and opportunities in a circular economy*, No 2020/1, European Topic Centre Waste and Materials in a Green Economy (https://www.eionet.europa.eu/etcs/etc-wmge/products/etc-wmge-reports/construction-and-demolition-waste-challenges-and-opportunities-in-a-circular-economy) accessed 24 April 2022.

ETC/WMGE, 2021, *Business models in a circular economy*, Eionet Report No 2/2021, European Topic Centre on Waste and Materials in a Green Economy (https://www.eionet.europa.eu/etcs/etc-wmge/products/business-models-in-a-circular-economy) accessed 26 November 2021.

EU, 2009, Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products (OJ L 285, 31.10.2009, pp. 10-35).

EU, 2014, Regulation (EU) No 1143/2014 of the European Parliament and of the Council of 22 October 2014 on the prevention and management of the introduction and spread of invasive alien species (OJ L 317, 4.11.2014, p. 35-55).

EU, 2019, 'Entogreen: using biomimicry to turn organic waste into fish food', European Circular Economy Stakeholder Platform (https://circulareconomy.europa.eu/platform/en/good-practices/entogreen-using-biomimicry-turn-organic-waste-fish-food).

EU, 2020, Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088 (OJ L 198, 22.6.2020, p. 13-43).

Eufic, 2021, 'Food waste in Europe: statistics and facts about the problem' (https://www.eufic.org/en/food-safety/article/food-waste-in-europe-statistics-and-facts-about-the-problem) accessed 15 December 2022.

European Commission, 2016, *European red list of habitats. Part 2, Terrestrial and freshwater habitats.*, Publications Office, LU.

European Commission, 2019, The European Green Deal (COM/2019/640 final).

European Commission, 2020a, A new circular economy action plan for a cleaner and more competitive Europe (COM(2020) 98 final).

European Commission, 2020b, Chemicals Strategy for Sustainability - Towards a Toxic-Free Environment (COM(2020) 667 final).

European Commission, 2020c, EU Biodiversity Strategy for 2030 Bringing nature back into our lives (COM(2020) 380 final).

European Commission, 2020d, *Farm to Fork Strategy - for a fair, healthy and environmentally-friendly food system* (https://food.ec.europa.eu/system/files/2020-05/f2f_action-plan_2020_strategy-info_en.pdf) accessed 8 July 2022.

European Commission, 2022a, 'Bioeconomy & Climate Change & Energy Policies' (https://knowledge4policy.ec.europa.eu/bioeconomy/bioeconomy-climate-change-energy-policies_en) accessed 8 July 2022.

European Commission, 2022b, EU strategy for sustainable and circular textiles (COM(2022) 141 final).

European Commission, 2022c, 'Microplastics' (https://environment.ec.europa.eu/topics/plastics/microplastics_en) accessed 12 December 2022.

European Construction Sector Observatory, 2018, *Improving energy and resource efficiency - Analytical Report*, European Commission.

Eurostat, 2022a, 'Energy statistics - an overview' (https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_statistics_-_an_overview) accessed 15 December 2022.

Eurostat, 2022b, 'Inability to afford a meal with meat, chicken, fish (or vegetarian equivalent) every second day (code ILC_MDES03)' (https://ec.europa.eu/eurostat/databrowser/view/ilc_mdes03/default/table?lang=en) accessed 15 December 2022.

Eurostat, 2022c, 'Waste statistics' (https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Waste_statistics) accessed 10 October 2022.

FAO and ICAC, 2013, *World Apparel Fiber Consumption Survey*, International Cotton Advisory Committee, Washington D.C.

Folk, E., 2021, 'The Environmental Impacts of Industrialization | EcoMENA' (https://www.ecomena.org/environmental-impacts-of-industrialization/) accessed 15 December 2022.

Forslund, T., 2021, 'The circular economy is key to halting biodiversity loss', Sitra (https://www.sitra.fi/en/articles/the-circular-economy-is-key-to-halting-biodiversity-loss/) accessed 1 April 2022.

Forslund, T., et al., 2022, *Tackling root causes – Halting biodiversity loss through the circular economy*, SITRA.

Fricke, K., et al., 2017, 'Recycling of Biowaste: Experience with Collection, Digestion, and Quality in Germany', in: *Maletz, R., Dornack, C., Ziyang, L. (eds) Source Separation and Recycling. The Handbook of Environmental Chemistry*, Springer, Cham.

Gao, J. and O'Neill, B. C., 2020, 'Mapping global urban land for the 21st century with data-driven simulations and Shared Socioeconomic Pathways', *Nature Communications* 11(1), p. 2302 (DOI: 10.1038/s41467-020-15788-7).

Gasparatos, A., et al., 2017, ‘Renewable energy and biodiversity: Implications for transitioning to a Green Economy’, *Renewable and Sustainable Energy Reviews* 70, pp. 161-184 (DOI: 10.1016/j.rser.2016.08.030).

Gillabel, J., et al., 2021, *Business models in a circular economy*, ETC/WMGE - Eionet Report No 2/2021, European Topic Centre on Waste and Materials in a Green Economy (https://www.eionet.europa.eu/etcs/etc-wmge/products/business-models-in-a-circular-economy) accessed 26 November 2021.

Giurco, D., et al., 2014, ‘Circular Economy: Questions for Responsible Minerals, Additive Manufacturing and Recycling of Metals’, *Resources* 3(2), pp. 432-453 (DOI: 10.3390/resources3020432).

González-Fernández, D., et al., 2021, ‘Floating macrolitter leaked from Europe into the ocean’, *Nature Sustainability* 4(6), pp. 474-483 (DOI: 10.1038/s41893-021-00722-6).

Granskog, A., et al., 2020, *Biodiversity: The next frontier in sustainable fashion*, McKinsey & Company (https://www.mckinsey.com/~/media/McKinsey/Industries/Retail/Our%20Insights/Biodiversity%20The%20next%20frontier%20in%20sustainable%20fashion/Biodiversity-The-next-frontier-in-sustainable-fashion-vF.pdf).

Graulich, K., et al., 2021, *Emerging waste streams – Challenges and opportunities* (https://www.oeko.de/fileadmin/oekodoc/EEA_emerging-waste-streams_final-report.pdf).

Green, J. M. H., et al., 2019, ‘Linking global drivers of agricultural trade to on-the-ground impacts on biodiversity’, *Proceedings of the National Academy of Sciences* 116(46), pp. 23202-23208 (DOI: 10.1073/pnas.1905618116).

Greenpeace, 2015, Wegwerfware Kleidung - Repräsentative Greenpeace-Umfrage zu Kaufverhalten, Tragedauer und der Entsorgung von Mode, (https://www.greenpeace.de/sites/default/files/publications/20151123_greenpeace_modekonsum_flyer.pdf) accessed 20 September 2022.

Grosse-Ophoff, A., et al., 2017, ‘How shared mobility will change the automotive industry’ (https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/how-shared-mobility-will-change-the-automotive-industry) accessed 1 December 2022.

Guillen, J., et al., 2019, ‘Global seafood consumption footprint’, *Ambio* 48(2), pp. 111-122 (DOI: 10.1007/s13280-018-1060-9).

Guitart, C., et al., 2019, *Mediterranean biodiversity and marine litter: an interaction knowledge base*, Interreg Med Biodiversity Protection project.

Habel, J. C. and Schmitt, T., 2018, ‘Vanishing of the common species: Empty habitats and the role of genetic diversity’, *Biological Conservation* 218, pp. 211-216 (DOI: 10.1016/j.biocon.2017.12.018).

Hall, M., 2020, ‘6 things you need to know about sand mining’, Mining Technology (https://www.mining-technology.com/features/six-things-sand-mining/) accessed 15 December 2022.

Heidenstrøm, N., et al., 2021, *Product lifetime in European and Norwegian policies*, Oslo Metropolitan University, Oslo, Norway (https://oda.oslomet.no/oda-xmlui/bitstream/handle/11250/2774663/SIFO-report%2011-2021%20Lasting.pdf?sequence=1&isAllowed=y) accessed 20 September 2022.

Hellwig, A., 2022, ‘The Circular Economy: A boon for Biodiversity Conservation?’, ISS Insights (https://insights.issgovernance.com/posts/the-circular-economy-a-boon-for-biodiversity-conservation/) accessed 16 December 2022.

Henry, M., et al., 2020, 'A typology of circular start-ups: Analysis of 128 circular business models', *Journal of Cleaner Production* 245, p. 118528 (DOI: 10.1016/j.jclepro.2019.118528).

House of Commons, 2019, *Fixing fashion: clothing consumption and sustainability* (https://publications.parliament.uk/pa/cm201719/cmselect/cmenvaud/1952/1952.pdf) accessed 10 April 2019.

Hulme, P. E., 2021, 'Unwelcome exchange: International trade as a direct and indirect driver of biological invasions worldwide', *One Earth* 4(5), pp. 666-679 (DOI: 10.1016/j.oneear.2021.04.015).

ICMM, 2022, 'Mining principles' (https://www.icmm.com/website/publications/pdfs/mining-principles/mining-principles.pdf?cb=10319) accessed 9 December 2022.

ILO, 2018, *World Employment and Social Outlook 2018: Greening with jobs*, Report, International Labour Organization, Geneva (http://www.ilo.org/global/research/global-reports/weso/2018/WCMS_615594/lang--en/index.htm) accessed 15 August 2019.

Ingarao, G., 2017, 'Manufacturing strategies for efficiency in energy and resources use: The role of metal shaping processes', *Journal of Cleaner Production* 142, pp. 2872-2886 (DOI: 10.1016/j.jclepro.2016.10.182).

IPBES, 2018, *The regional assessment report on biodiversity and ecosystem services for Europe and Central Asia — Summary for policymakers*, Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) Secretariat, Bonn, Germany (https://www.ipbes.net/system/tdf/spm_2b_eca_digital_0.pdf?file=1&type=node&id=28318).

IPBES, 2019, *Global assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*, Brondízio, E. S., Settele, J., Díaz, S., Ngo, H. T. (eds)., IPBES secretariat, Bonn, Germany.

IPCC, 2022, *Climate Change 2022: Mitigation of Climate Change - Working Group III contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Intergovernmental Panel on Climate (https://www.ipcc.ch/report/sixth-assessment-report-working-group-3/) accessed 6 April 2022.

IRP, 2018, *The weight of cities: resource requirements of future urbanization*, International Resource Panel — United Nations Environment Programme, Nairobi, Kenya (https://www.resourcepanel.org/reports/weight-cities) accessed 1 July 2019.

IRP, 2019, *Global Resources Outlook 2019: Natural Resources for the Future We Want*, International Resource Panel, Nairobi, Kenya (https://www.resourcepanel.org/reports/global-resources-outlook) accessed 1 April 2022.

IUCN, 2018, Invasive alien species and sustainable development, (https://www.iucn.org/sites/default/files/2022-07/ias_and_sustainable_development_issues_brief_final.pdf) accessed 21 December 2022.

Ives, C. D., et al., 2016, 'Cities are hotspots for threatened species', *Global Ecology and Biogeography* 25(1), pp. 117-126 (DOI: 10.1111/geb.12404).

Jaureguiberry, Pedro, et al., 2022, 'The direct drivers of recent global anthropogenic biodiversity loss', (DOI: 10.5281/ZENODO.7097953).

Johnson, D., 2019, 'Circular cities of the world: what can green infrastructure do?', The Conversation (http://theconversation.com/circular-cities-of-the-world-what-can-green-infrastructure-do-119273) accessed 6 December 2022.

Jones, N. F., et al., 2015, 'The Energy Footprint: How Oil, Natural Gas, and Wind Energy Affect Land for Biodiversity and the Flow of Ecosystem Services', *BioScience* 65(3), pp. 290-301 (DOI: 10.1093/biosci/biu224).

Kettunen, M., et al., 2020, *An EU Green Deal for trade policy and the environment: Aligning trade with climate and sustainable development objectives.*, IEEP, Brussels / London (https://ieep.eu/uploads/articles/attachments/9c951784-8c12-4ff5-a5c5-ee17c5f9f80b/Trade%20and%20environment_FINAL%20(Jan%202020).pdf).

Kirchherr, J., et al., 2017, 'Conceptualizing the circular economy: an analysis of 114 definitions', *Resources, Conservation and Recycling* 127, pp. 221-232 (DOI: https://doi.org/10.1016/j.resconrec.2017.09.005).

Kissinger, M., et al., 2013, 'Accounting for Greenhouse Gas Emissions of Materials at the Urban Scale-Relating Existing Process Life Cycle Assessment Studies to Urban Material and Waste Composition', *Low Carbon Economy* 04(01), pp. 36-44 (DOI: 10.4236/lce.2013.41004).

Klemetti, E., 2020, 'Tracking the Source of Illegal Sand Mining', Discover Magazine (https://www.discovermagazine.com/planet-earth/tracking-the-source-of-illegal-sand-mining) accessed 15 December 2022.

Köhler, A., et al., 2021, *Circular economy perspectives in the EU textile sector*, Publications Office of the European Union, Luxembourg (https://publications.jrc.ec.europa.eu/repository/handle/JRC125110) accessed 31 January 2023.

Koszewska, M., 2018, 'Circular economy - challenges for the textile and clothing industry', *Autex Research Journal* 18(4), pp. 337-347 (DOI: 10.1515/aut-2018-0023).

Kumar, M. and Mani, M., 2021, 'Chapter 11 - Sustainability assessment in manufacturing: perspectives, challenges, and solutions', in: Gupta, K. and Salonitis, K. (eds), *Sustainable Manufacturing*, Handbooks in Advanced Manufacturing, Elsevier, pp. 287-311.

Kurth, T., et al., 2021, *The Biodiversity Crisis Is a Business Crisis* (https://web-assets.bcg.com/fb/5e/74af5531468e9c1d4dd5c9fc0bd7/bcg-the-biodiversity-crisis-is-a-business-crisis-mar-2021-rr.pdf) accessed 4 February 2022.

Leader's Pledge for Nature, 2020, United to Reverse Biodiversity Loss by 2030 for Sustainable Development, (https://www.leaderspledgefornature.org/wp-content/uploads/2021/06/Leaders_Pledge_for_Nature_27.09.20-ENGLISH.pdf) accessed 6 December 2022.

Leclère, D., et al., 2020, 'Bending the curve of terrestrial biodiversity needs an integrated strategy', *Nature* 585(7826), pp. 551-556 (DOI: 10.1038/s41586-020-2705-y).

Lehtiniemi, M., et al., 2005, 'Turbidity decreases anti-predator behaviour in pike larvae, Esox lucius', *Environmental Biology of Fishes* 73(1), pp. 1-8 (DOI: 10.1007/s10641-004-5568-4).

Li, G., et al., 2022, 'Global impacts of future urban expansion on terrestrial vertebrate diversity', *Nature Communications* 13(1), p. 1628 (DOI: 10.1038/s41467-022-29324-2).

Li, H. and Feng, K., 2018, 'Life cycle assessment of the environmental impacts and energy efficiency of an integration of sludge anaerobic digestion and pyrolysis', *Journal of Cleaner Production* 195, pp. 476-485 (DOI: 10.1016/j.jclepro.2018.05.259).

Lin, B. B., et al., 2015, 'The future of urban agriculture and biodiversity-ecosystem services: Challenges and next steps', *Basic and Applied Ecology* 16(3), pp. 189-201 (DOI: 10.1016/j.baae.2015.01.005).

Linz, M., et al., 2002, *Von nichts zu viel - Suffizienz gehört zur Zukunftsfähigkeit*, Wuppertal Institut für Klima, Umwelt, Energie, Wuppertal, Germany (https://epub.wupperinst.org/frontdoor/deliver/index/docId/1512/file/WP125.pdf) accessed 20 September 2022.

López, V. and Teufel, J., 2022, Integrating biodiversity into sustainable production and consumption activities - The way forward for business, One Planet.

Maes, J., et al., 2020, *Mapping and assessment of ecosystems and their services: an EU wide ecosystem assessment in support of the EU biodiversity strategy*, Publications Office of the European Union, Luxembourg.

Makov, T. and Fitzpatrick, C., 2021, 'Is repairability enough? big data insights into smartphone obsolescence and consumer interest in repair', *Journal of Cleaner Production* 313, p. 127561 (DOI: 10.1016/j.jclepro.2021.127561).

Mammadova, A., et al., 2022, 'Deforestation as a Systemic Risk: The Case of Brazilian Bovine Leather', *Forests* 13(2) (DOI: 10.3390/f13020233).

Material Economics, 2018, *The circular economy: a powerful force for climate mitigation*, Material Economics Sverige, Stockholm (https://materialeconomics.com/publications/the-circular-economy-a-powerful-force-for-climate-mitigation-1) accessed 16 July 2019.

Material Economics, et al., 2021, 'EU Biomass use in a Net-zero Economy' (https://materialeconomics.com/publications/eu-biomass-use) accessed 10 August 2022.

Maxwell, D., et al., 2015, *The State of the Apparel Sector 2015 Special Report—Water*, Report for the Global Leadership Award in Sustainable Apparel (http://glasaaward.org/wp-content/uploads/2015/05/GLASA_2015_StateofApparelSector_SpecialReport_Water_150624.pdf).

MEA, 2005, *Ecosystems and human well-being: synthesis*, Millennium Ecosystem Assessment, World Resources Institute, Washington, DC, USA (https://www.millenniumassessment.org/documents/document.356.aspx.pdf) accessed 6 August 2019.

Mikkelsen, L. and Ege, C., 2015, *Anvendelse af organisk affald i biogasanlæg*, Det Økologiske Råd, Copenhagen (https://ens.dk/sites/ens.dk/files/Bioenergi/vurdering_af_stoffer_-_bilagsrapport.pdf) accessed 16 December 2022.

Mikkola, N., et al., 2016, *Green growth in Nordic regions – 50 ways to make it happen*, Nordregio, Stockholm, Sweden (https://archive.nordregio.se/Global/Green%20growth%20in%20Nordic%20regions%2050/NordicGreenGrowth-pages.pdf).

Mishra, S., et al., 2019, 'Marine microfiber pollution: A review on present status and future challenges', *Marine Pollution Bulletin* 140, pp. 188-197 (DOI: 10.1016/j.marpolbul.2019.01.039).

Mud Jeans, 2020, *Mud Jeans Sustainability Report 2020* (https://cdn.shopify.com/s/files/1/0432/6427/8679/files/MUD_Jeans_Sustainability_Report_2020_Online.pdf?v=1626790590) accessed 20 September 2022.

Niinimäki, K., et al., 2020, 'Author Correction: The environmental price of fast fashion', *Nature Reviews Earth & Environment* 1(5), pp. 278-278 (DOI: 10.1038/s43017-020-0054-x).

Notarnicola, B., et al., 2017, 'Environmental impacts of food consumption in Europe', *Journal of Cleaner Production* 140, pp. 753-765 (DOI: 10.1016/j.jclepro.2016.06.080).

Núñez-Regueiro, M. M., et al., 2021, 'Effects of bioenergy on biodiversity arising from land-use change and crop type', *Conservation Biology* 35(1), pp. 77-87 (DOI: 10.1111/cobi.13452).

O'Brien, M., et al., 2015, 'The land footprint of the EU bioeconomy: Monitoring tools, gaps and needs', *Land Use Policy* 47, pp. 235-246 (DOI: 10.1016/j.landusepol.2015.04.012).

OECD, 2019, *Biodiversity: Finance and the Economic and Business Case for Action*, OECD.

One Planet Network, 2021, 'Natural-Resource Use and Environmental Impacts', One Planet network (https://www.oneplanetnetwork.org/SDG-12/natural-resource-use-environmental-impacts) accessed 1 December 2022.

OVAM, 2019, *Circulaire economie en de Vlaamse klimaatdoelstellingen. Voedings- en textielsysteem.*

Paajanen, T., et al., 2021, 'Protect biodiversity with circular solutions', Sitra (https://www.sitra.fi/en/articles/protect-biodiversity-with-circular-solutions/) accessed 29 March 2022.

Pearlmutter, D., et al., 2020, 'Enhancing the circular economy with nature-based solutions in the built urban environment: green building materials, systems and sites', *Blue-Green Systems* 2(1), pp. 46-72 (DOI: 10.2166/bgs.2019.928).

Peñate-Valentín, M. C., et al., 2021, 'The promotion of innovative service business models through public procurement. An analysis of Energy Service Companies in Spain', *Sustainable Production and Consumption* 27, pp. 1857-1868 (DOI: 10.1016/j.spc.2021.04.028).

Pendrill, F., et al., 2019, 'Agricultural and forestry trade drives large share of tropical deforestation emissions', *Global Environmental Change* 56, pp. 1-10 (DOI: 10.1016/j.gloenvcha.2019.03.002).

Pereira, H. M., et al., 2010, 'Scenarios for global biodiversity in the 21st century', *Science* 330(6010), pp. 1496-1501 (DOI: 10.1126/science.1196624).

Persson, L., et al., 2022, 'Outside the Safe Operating Space of the Planetary Boundary for Novel Entities', *Environmental Science & Technology* 56(3), pp. 1510-1521 (DOI: 10.1021/acs.est.1c04158).

Pörtner, H.-O., et al., 2021, *Scientific outcome of the IPBES-IPCC co-sponsored workshop on biodiversity and climate change*, Zenodo (https://zenodo.org/record/4659158) accessed 6 December 2022.

Potting, J., et al., 2017, *Circular Economy: Measuring innovation in the product chain - Policy report*, No PBL publication number: 2544, PBL Netherlands Environmental Assessment Agency, The Hague (https://www.pbl.nl/sites/default/files/downloads/pbl-2016-circular-economy-measuring-innovation-in-product-chains-2544.pdf) accessed 28 March 2022.

Princen, T., 2005, *The Logic of Sufficiency*, MIT Press, Cambridge, Massachusetts.

Putt del Pino, S., et al., 2017, *The Elephant in the Boardroom: Why Unchecked Consumption Is Not an Option in Tomorrow's Markets*, World Resources Institute, Washington D.C. (https://www.wri.org/research/elephant-boardroom-why-unchecked-consumption-not-option-tomorrows-markets).

Remy, N., et al., 2016, 'Style that's sustainable: A new fast-fashion formula | McKinsey' (https://www.mckinsey.com/business-functions/sustainability/our-insights/style-thats-sustainable-a-new-fast-fashion-formula) accessed 13 February 2019.

Ritchie, H., 2022, 'How does the land use of different electricity sources compare?', Our World in Data (https://ourworldindata.org/land-use-per-energy-source) accessed 15 December 2022.

Runhaar, H., 2017, 'Governing the transformation towards "nature-inclusive" agriculture: insights from the Netherlands', *International Journal of Agricultural Sustainability* 15(4), pp. 340-349 (DOI: 10.1080/14735903.2017.1312096).

Sajn, N., 2019, Environmental impact of textile and clothes industry, (https://www.europarl.europa.eu/RegData/etudes/BRIE/2019/633143/EPRS_BRI%282019%29633143_EN.pdf), European Parliamentary Research Service.

Šajn, N., 2022, Right to repair - European Parliament Briefing, (https://www.europarl.europa.eu/RegData/etudes/BRIE/2022/698869/EPRS_BRI(2022)698869_EN.pdf) accessed 11 April 2022, European Parliamentary Research Service.

San-Miguel-Ayan, J., et al., 2022, *Advance report on wildfires in Europe, Middle East and North Africa 2021.*, Publications Office of the European Union, LU.

Santana Marques, P., et al., 2020, 'Urbanization can increase the invasive potential of alien species', *Journal of Animal Ecology* 89(10), pp. 2345-2355 (DOI: 10.1111/1365-2656.13293).

Schrems, I. and Bär, H., 2021, *Introduction to the EU Taxonomy on Biodiversity and Ecosystems*, Forum Ökologisch-Soziale Marktwirtschaft (FÖS) (https://www.nabu.de/imperia/md/content/nabude/sustainablefinance/210412_nabu_taxonomy_biodiversity-and-ecosystems.pdf).

Schröder, P., et al., 2021, 'The role of the circular economy in addressing the global biodiversity crisis', CircularEconomy.Earth (https://circulareconomy.earth/publications/the-role-of-the-circular-economy-in-addressing-the-global-biodiversity-crisis) accessed 1 April 2022.

Schüch, A., et al., 2019, 'Technological options for biogenic waste and residues — overview of current solutions and developments', in: Ghosh, S. K. (ed.), *Waste valorisation and recycling*, Springer Singapore, pp. 307-322.

Schultz, T. and Suresh, A., 2017, 'Life Cycle Assessment Comparing Ten Sources of Manmade Cellulose Fiber', *SCS Global Service Final Report*, p. 158.

Science-based targets Network, 2020, *Science-based targets for nature - Initial Guidance for Business* (https://sciencebasedtargetsnetwork.org/wp-content/uploads/2020/09/SBTN-initial-guidance-for-business.pdf) accessed 12 April 2022.

Secretariat of the Convention on Biological Diversity, 2020, *Global Biodiversity Outlook 5 - Summary for Policymakers*, Montréal, Canada (https://www.cbd.int/gbo/gbo5/publication/gbo-5-spm-en.pdf) accessed 8 July 2022.

Seiler, A. and Bhardwaj, M., 2020, 'Wildlife and Traffic: An Inevitable but Not Unsolvable Problem?', in: Angelici, F. M. and Rossi, L. (eds), *Problematic Wildlife II: New Conservation and Management Challenges in the Human-Wildlife Interactions*, Springer International Publishing, Cham, pp. 171-190.

SITRA and Circle Economy, 2015, *Service-based business models & circular strategies for textiles* (https://s3-eu-west-1.amazonaws.com/stjm/20160330092502/Service-based-business-models-and-circular-strategies-for-textiles-2015-SITRA-STJM.pdf) accessed 4 September 2019.

Sordello, R., et al., 2020, 'Evidence of the impact of noise pollution on biodiversity: a systematic map', *Environmental Evidence* 9(1), p. 20 (DOI: 10.1186/s13750-020-00202-y).

Steffen, W., et al., 2015, 'Planetary boundaries: guiding human development on a changing planet', *Science* 347(6223), p. 1259855 (DOI: 10.1126/science.1259855).

Stegmann, P., et al., 2020, 'The circular bioeconomy: Its elements and role in European bioeconomy clusters', *Resources, Conservation & Recycling: X* 6, p. 100029 (DOI: 10.1016/j.rcrx.2019.100029).

Stengel, O., 2011, 'Less Is More Difficult. Why Sufficient Lifestyles Have a Rough Ride – And How We Can Promote Them', *GAIA - Ecological Perspectives for Science and Society* 20(1), pp. 26-30 (DOI: 10.14512/gaia.20.1.7).

Sun, Z., et al., 2022, 'Global Human Consumption Threatens Key Biodiversity Areas', *Environmental Science & Technology* 56(12), pp. 9003-9014 (DOI: 10.1021/acs.est.2c00506).

SveMin, 2020, 'MINING WITH NATURE - The Swedish mining and minerals industry's road map for biodiversity net gain' (https://www.euromines.org/files/svemin_miningwithnature_eng_2020-11-10_lagupplost.pdf) accessed 9 December 2022.

Tekman, M. B., et al., 2022, *Impacts of plastic pollution in the oceans on marine species, biodiversity and ecosystems*, Zenodo (https://zenodo.org/record/5898684) accessed 10 June 2022.

Torres, A., et al., 2017, 'A looming tragedy of the sand commons', *Science* 357(6355), pp. 970-971 (DOI: 10.1126/science.aao0503).

Trivedi, J., et al., 2015, 'Algae based biorefinery — How to make sense?', *Renewable and Sustainable Energy Reviews* 47(Supplement C), pp. 295-307 (DOI: 10.1016/j.rser.2015.03.052).

Tubiello, F. N., et al., 2022, 'Pre- and post-production processes increasingly dominate greenhouse gas emissions from agri-food systems', *Earth Syst. Sci. Data* 14(4), pp. 1795-1809 (DOI: 10.5194/essd-14-1795-2022).

Tzanopoulos, J., et al., 2013, 'Scale sensitivity of drivers of environmental change across Europe', *Global Environmental Change* 23(1), pp. 167-178 (DOI: 10.1016/j.gloenvcha.2012.09.002).

UKEssays, 2018, 'What are the impacts of aquaculture on biodiversity?' (https://www.ukessays.com/essays/environmental-studies/impacts-aquaculture-biodiversity-3000.php?vref=1).

UNEP, 2011, *Towards a green economy: Pathways to sustainable development and poverty eradication*, United Nations Environment Programme, Nairobi, Kenya (https://sustainabledevelopment.un.org/index.php?page=view&type=400&nr=126&menu=35) accessed 15 August 2018.

UNEP, 2022, Stockholm 50+ Presidents´ Final Remarks to Plenary Key recommendations for accelerating action towards a healthy planet for the prosperity of all, (https://wedocs.unep.org/bitstream/handle/20.500.11822/40110/Key%20Messages%20and%20Recommendations%20-%20Formatted.pdf?sequence=1&isAllowed=y) accessed 6 December 2022.

UNEP and One Earth, 2018, *Sustainable Lifestyles: Options and Opportunities*, UN Environment, Paris.

United Nations, 2020, Alongside Pandemic, World Faces 'Triple Planetary Emergency', Secretary-General Tells World Forum for Democracy, Citing Climate, Nature, Pollution Crises | UN Press, (https://press.un.org/en/2020/sgsm20422.doc.htm) accessed 6 December 2022.

United Nations Department of Economic and Social Affairs, 2021, Circular agriculture for sustainable rural development, (https://www.un.org/development/desa/dpad/wp-content/uploads/sites/45/publication/PB_105.pdf).

US EPA, O., 2014, 'Persistent Organic Pollutants: A Global Issue, A Global Response' (https://www.epa.gov/international-cooperation/persistent-organic-pollutants-global-issue-global-response) accessed 21 September 2022.

van den Berge, R., et al., 2021, 'Too good to go? Consumers' replacement behaviour and potential strategies for stimulating product retention', *Current Opinion in Psychology* 39, pp. 66-71 (DOI: 10.1016/j.copsyc.2020.07.014).

Vittuari, M., et al., 2016, *Recommendations and guidelines for a common European food waste policy framework*, Fusions, Bologna, Italy (https://www.eu-fusions.org/phocadownload/Publications/D3.5%20recommendations%20and%20guidelines%20food%20waste%20policy%20FINAL.pdf) accessed 17 October 2017.

Walker, T. R., et al., 2019, 'Environmental Effects of Marine Transportation', in: Sheppard, C. (ed.), *World Seas: An Environmental Evaluation (Second Edition)*, Academic Press, pp. 505-530.

Wang, H., et al., 2021, 'Eutrophication causes invertebrate biodiversity loss and decreases cross-taxon congruence across anthropogenically-disturbed lakes', *Environment International* 153, p. 106494 (DOI: 10.1016/j.envint.2021.106494).

WBCSD, 2019, 'Nineteen leading companies join forces to step up alternative farming practices and protect biodiversity, for the benefit of planet and people', World Business Council for Sustainable Development (WBCSD) (https://www.wbcsd.org/ygomd) accessed 16 December 2022.

Westerholm, N., 2020, *State of Play for Circular Built Environment in Europe. A report compiling the regional state of play for circularity in the built environment in Europe across the member states of the European Union, Iceland, Norway, Serbia and the United Kingdom*, United Nations One Planet Network Sustainable Buildings and Construction Programme (https://www.oneplanetnetwork.org/sites/default/files/europe_final_201030.pdf) accessed 6 December 2022.

Wiens, J. A. and Hobbs, R. J., 2015, 'Integrating Conservation and Restoration in a Changing World', *BioScience* 65(3), pp. 302-312 (DOI: 10.1093/biosci/biu235).

World Bank, 2013, *Fish to 2030: prospects for fisheries and aquaculture*, Report No 83177, World Bank, Washington, DC.

World Bank, 2014, *The Bangladesh Responsible Sourcing Initiative : A new model for green growth*, World Bank Group, Washington D.C. (http://documents.worldbank.org/curated/en/614901468768707543/The-Bangladesh-Responsible-Sourcing-Initiative-A-new-model-for-green-growth).

World Benchmarking Alliance, 2022, 'Nature is a blind spot for major companies despite its importance for their operations and people', World Benchmarking Alliance (https://www.worldbenchmarkingalliance.org/news/nature-benchmark-press-release-2022/) accessed 9 December 2022.

World Economic Forum, 2016, *Shaping the future of construction: A breakthrough in mindset and technology*, World Economic Forum, Geneva, Switzerland (https://www3.weforum.org/docs/WEF_Shaping_the_Future_of_Construction_full_report__.pdf).

World Economic Forum, 2020a, *New Nature Economy* (https://www3.weforum.org/docs/WEF_New_Nature_Economy_Report_2020.pdf) accessed 8 February 2022.

World Economic Forum, 2020b, *The future of nature and business* (https://www3.weforum.org/docs/WEF_The_Future_Of_Nature_And_Business_2020.pdf) accessed 8 February 2022.

World Resources Forum, 2015, 'Planet Earth and its limits on the use of natural resources', World Resources Forum (https://www.wrforum.org/opinion/planet-earth-limits-natural-resources/) accessed 2 December 2022.

WWF, 2014, 'Handle with Care', *World Wildlife Magazine*, 2014 (https://www.worldwildlife.org/magazine/issues/spring-2014/articles/handle-with-care) accessed 19 December 2022.

WWF, 2022a, *Beyond Forests - Reducing the EU´s footprint on all natural ecosystems*, WWF, Gland, Switzerland (https://wwfeu.awsassets.panda.org/downloads/beyond_forests_en.pdf) accessed 15 December 2022.

WWF, 2022b, *Living Planet Report 2022 - Building a nature-positive society*, WWF, Gland, Switzerland (https://www.wwf.org.uk/sites/default/files/2022-10/lpr_2022_full_report.pdf) accessed 15 December 2022.

European Topic Centre on
Circular economy and resource use
https://www.eionet.europa.eu/etcs/etc-ce

The European Topic Centre on Circular economy and resource use (ETC CE) is a consortium of European institutes under contract of the European Environment Agency.