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Alpine Space

PlanToConnect

D.1.3.1 Threats report on alpine ecological connectivity, renewable energies and upcoming spatial needs

Identification of major emerging threats posed to GBI ecological networks integrity and connectivity function, focusing on increasing renewable energy production

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D.1.3.1 Threats report on alpine ecological connectivity, renewable energies and upcoming spatial needs

Identification of major emerging threats posed to GBI ecological networks integrity and connectivity function, focusing on increasing renewable energy production

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1 Introduction

PlanToConnect - Project overall objective

Promoting ecological connectivity is an important element to enable dynamic adaptation processes in ecosystems, and thus to combat the decline in biodiversity and preserve ecosystem functions, especially in view of changing climatic conditions. While protected areas are well established, their connection through green and blue infrastructure/ecological corridors suffers from significant planning gaps, missing implementation, and continued or newly emerging threats such as transport infrastructure, settlement development and the expansion of renewable energies. An overarching connectivity planning concept guiding corridor implementation across Alpine regions is currently missing.

The aim of the PlanToConnect project is to develop and test an Alpine spatial planning strategy for ecological connectivity in cooperation with stakeholders in pilot areas. Proposals for the upgrade of spatial planning systems and territorial policies will be developed. This threats report represents a preparatory step towards ecological network design in pilot regions as well as towards formulation of the Alpine spatial planning strategy.

"Connectivity comprises two components, structural and functional connectivity. It expresses how landscapes are configurated, allowing species to move. Structural connectivity, equal to habitat continuity, is measured by analysing landscape structure, independent of any attributes of organisms. […]. Functional connectivity is the response of the organism to the landscape elements other than its habitats (i.e. the non-habitat matrix). This definition is often used in the context of landscape ecology. A high degree of connectivity is generally linked to low fragmentation." (EUROPEAN COMMISSION - Technical information on Green Infrastructure (GI), 6.5.2013, Glossary)

(Definition of connectivity see also Deliverable 1.1.1, chapter 8)

General threats to biodiversity

According to the "Global Assessment Report on Biodiversity and Ecosystem Services" (Díaz et al. 2019), major threats to biodiversity loss in terrestrial ecosystems comprise in descending order:

- Land use changes (increasing sealing, large-scale development, loss of structural diversity in the landscape, fragmentation, intensive monocultures …),
- direct exploitation of natural resources,
- climate change,
- pollution,
- and invasive alien species.

The biggest driver of biodiversity loss is how people use the land. This includes the conversion of land covers such as forests, wetlands and other natural habitats for agricultural, touristic, energy, settlement and transport infrastructure. A detailed description of the most important anthropogenic pressures is given in Deliverable D1.2.1. (Transnational inventory of alpine GBI network elements with compatible and conflicting uses).

Deliverable D.1.3.1: Threats report on alpine ecological connectivity, renewable energies and upcoming spatial needs.

In order to maintain or create a functioning green and blue infrastructure (GBI), the threats that have an impact on connectivity must be known. These impacts are, as shown above, primarily the result of widespread land use change, fragmentation, intensification, urbanisation and other developments.

In addition to intensive agriculture and forestry (which will be discussed in Deliverable 1.2.1), increasing settlement activity and the development of transport and energy infrastructures are responsible for the loss of biodiversity.

As part of PlanToConnect's Work Package 1 "Knowledge base for green and blue infrastructure (GBI) connectivity planning" the major emerging threats posed to GBI ecological networks will be described and assessed below (chapter 2). Because there is an increasing demand for energy, especially for renewable energies, the report focuses on renewable energies and their potential conflicts with ecological connectivity. It provides a general basis for the case studies in Activity A2.4.

In a further report of Activity 1.3.1 (Policy Analysis) the upcoming sectoral policy developments and in particular the emerging threats from the development of renewable energy installations are analysed.

In this report the following sectors are analysed:

Table 1: Analysed threats

Sector	Type of infrastructure/ Land use
Renewable energy	Hydropower - Hydroelectric reservoir (dam)
	Hydropower - Run-off-River power plant
	Windpower - windmills
	Solar Power - Photovoltaics: Ground-mounted solar panels
	Bioenergy - Biomass
Energy sector as a whole	Transmission of electricity - High voltage transmission line
Transport	Roads/ Highways
	Railway
Urban /industrial development	Urban/ industrial development

The following questions are to be answered:

- What are the major impacts of a certain type of infrastructure or land use on biodiversity and particularly on connectivity?
- Which locations are suitable or unsuitable in terms of connectivity?
- Are there possibilities of mitigation or compensation?

In many cases, effects during the construction period of a facility have a strong influence on connectivity. Because these construction-related impacts are only temporary and cannot generally predicted they are not considered in this report. Only permanent facility- or operation-related impacts on connectivity are considered subsequently.

For all kinds of energy production or transport systems an appropriate access infrastructure like roads, power lines etc. are necessary. This means that not only the facility itself but also the infrastructure it requires contribute to further land take and landscape fragmentation. This is particularly a problem for alpine regions. Usually the access infrastructure is not so much developed in higher altitudes than in flat areas. This has to be taken into account especially when energy plants are in remote areas.

2 Major threats to ecological connectivity (structural and functional connectivity)

2.1 Hydropower

In principle, a distinction is made between “hydroelectric reservoirs including a dam” and “run-off-river power plants”. Hydroelectric reservoirs use water from a reservoir to generate electricity. The run-off-river power plant uses the natural flow of rivers and streams. In order to increase the potentially usable energy, damming by a weir usually takes place.

Figure 1: Hydroelectric reservoir (dam) and run-off-river power plant

2.1.1 Environmental impacts of hydropower

In Europe hydropower has been utilised for centuries, often operating on the basis of old water rights. Therefore, the impact of many hydropower plants and the associated structures (e.g. roads) took place a long time ago. In some cases, new habitats have developed since the construction of the facilities, which can sometimes be just as worthy of protection as the original state of the watercourse (e.g. “Innstauseen” in Bavaria and Upper Austria, as a habitat for waterfowl of international importance). On the other hand, hydropower facilities have large environmental impacts by changing the environment and affecting the land use (Meister 2023; Peters et al. 2011).

Until around twenty years ago, water protection in Europe played a significantly less important role than it does today. Since the beginning of the 1990s water protection regulations (residual water volumes, hydropeaking, bedload transport, passage of fish and aquatic organisms) have become more important. Therefore, the construction of new plants is now subject to much stricter conditions. The situation, with regard to existing older facilities, is becoming less acute as these increasingly have to be adapted to today's regulations (Volken et al. 2011). Numerous efforts have been undertaken during the past decades to improve upstream fish movements (e.g. fish passages) and decrease turbine related mortality (intelligent turbine design) (Balest et al. 2015).

The most relevant impact of hydroelectric reservoirs or run-off-river power plants is the **interruption of the biological and morphodynamic continuity of flowing waters**. Watercourses represent a type of habitat that is characterised in particular by dynamics and continuity. Many aquatic organisms are directly dependent on these habitat conditions so that the disruption of dynamics and continuity can lead to the displacement and eventual extinction of many species (Peters et al. 2011). Dams or weirs are physical barriers preventing or restricting the upstream and downstream migration of fish and invertebrates. For example, some species of fish depend on inland rivers for reproduction. As river flows are blocked with dams, fish cannot reach their breeding grounds. Over time, dammed rivers lead to drastically reduced fish populations, which has negative implications for the health of river ecosystems. Dams regulate water flow and disrupt natural flow cycles, creating homogenized, disturbed conditions that favour the spread of non-native species that in turn can threaten native species. The shift from lotic (fast-flowing) to lentic (still) waters favours generalist species which can displace range-restricted endemic species (Gibson et al. 2017). There is also the problem of direct damage of organisms passing the turbine plant. Several consecutive hydropower plants on a river course pose an increased risk and can lead to the endangerment of populations.

Hydroelectric dams or run-off-river power plants create also **physical barriers to downriver sediment flow**. The interruption of the sediment flux continuity is highly relevant, with consequent alteration of the geomorphological features (upstream and downstream of the dam/weir). Accumulation of sediments in the reservoir generates several adverse consequences upstream, such as loss of storage capacity, bottom outlet obstruction, abrasion risk on intakes and hydraulic turbines. River sediment accumulation also poses a challenge towards increased flood risks (Quaranta et al. 2023). Particularly in the Alps retreating glaciers will increase the sediment yield and reservoir sedimentation, thereby decreasing reservoir volume and energy production. Potential avalanches, rock falls, icefalls, or landslides into existing reservoirs or newly developing glacial lakes may trigger impulse waves and hazardous flood waves (Gurung et al. 2016). Besides increased sedimentation due to the reduced flow velocity, dams lead to an increase in water temperature and degradation of water quality in the reservoir. This has negative impacts on fish, birds and other wildlife. Accumulation of sediments upstream of dams reduces downstream fertilization due to lack of sediments and nutrients. It leads to erosion and deepening below the weir (erosion and incision of river channels downstream, loss of areas exposed to regular inundation). This causes impacts on downstream river ecosystems (Quaranta et al. 2023). In operation, accumulated sediments at weirs and water catchment facilities need to be flushed downstream in regular intervals (technical term “sand flushing”), destroying and overlaying downstream habitats in the process.

Additionally, damming rivers and water derivations often reduce water and sediment flow to dangerous levels, which impacts downstream wildlife populations (insufficient water discharge in the remaining riverbed) as well as the irrigation potential of Alpine rivers for agriculture during the growth season.

The nature and the size of all these impacts depend on management procedures such as maintaining in-stream flow, reducing hydro peaking, reservoir management, bed-load management (Balest et al. 2015).

Another relevant impact caused by hydropower is the **habitat loss due to impoundment reservoirs**. Hydroelectric reservoirs cover usually a large area replacing important lowland and riverine forest and grassland habitats (Gibson et al. 2017). This results also in visual impacts on the landscape.

Hydropower can also generate greenhouse gases, such as carbon dioxide (CO2) and methane (CH4) (Gibson et al. 2017). Methane and carbon dioxide are mainly generated as a consequence of the decomposition of organic matter in anaerobic conditions at the bottom of a hydropower reservoir, depending on the geographic context, climate and reservoir type. From Alpine hydropower reservoirs, only minor methane emissions are known (Diem et al. 2008; Quaranta et al. 2023; Sollberger et al. 2017). The construction of new reservoirs in Alpine valleys is often related to the removal of bogs and other wetland habitats that compose Alpine valley bottoms, setting off greenhouse gases emissions.

Secondary impacts refer to the access infrastructure (roads, construction areas, transmission lines …) causing removal of vegetation and habitat destruction of the local fauna. Many new hydropower dams require networks of roads for dam construction and maintenance that in turn increase deforestation and forest colonization.

Additional impacts are expected due to **hydropeaking** operations of a hydropower plant. This is the discontinuous release of water to accommodate peaks of energy demand, a scheme used to provide more flexible energy production. This practice results in highly fluctuating downstream flows. Although river flows have a natural variation. Fluctuations at the subdaily scale caused by hydropower plants are far more severe and impact the downstream river ecosystems. Fish populations face degradation of habitat and increased mortality due to stranding caused by a rapid fluctuation of the water level. Benthic populations face the risk of drifting due to high differences in water velocities. Riparian plants face both physiological and physical constraints because of the shifts between submergence and drainage and the erosion of substrates. There are further physical stressors caused by hydropeaking, such as temperature anomalies and modification in the sediment dynamics (Anindito et al. 2019). Altogether, the artificial flow and water level fluctuations downstream of the dam causes damages to the aquatic life, riparian vegetation and river morphology (Quaranta et al. 2023).

Another special type of hydropower, found mainly in the Alps and playing an important role for the management of energy peak production and demand in the energy transition towards renewables, are **Pumped Storage Hydropower Plants** (PSHP). It is a configuration of two water reservoirs at different elevations that can generate power as water moves down from one to the other (discharge), passing through a turbine. The system also requires power as it pumps water back into the upper reservoir (recharge). Meanwhile the primary service of pumped storage hydropower plants is the storage and release of surplus electricity and not electricity production per se (Gurung et al. 2016). The main impacts from Pumped Storage Hydropower Plants for downstream river areas include altered sediment transport, water withdrawal and hydropeaking (Gurung et al. 2016). Surge-sink-operations destroy habitats and threaten species through rapidly growing and receding water levels.

Besides these ecological impacts, the consequences for water regulation and flood protection also need to be discussed: On the one hand, experience from the past decades has demonstrated the ability of man-made reservoirs to defuse extreme flood events, but on the other hand these reservoirs can cause additional damage through mismanagement of water flow. Besides flood hazard protection, hydropower reservoirs may be important for the mitigation of droughts caused by regional climate change in the future (Balest et al. 2015).

2.1.2 Suitable locations

It is difficult to define suitable areas for hydropower. Only watercourses that are already degraded should be considered. On the other hand, the Water Framework Directive requires an improvement in the ecological status of already degraded watercourses which contradicts the construction of hydropower plants.

2.1.3 Unsuitable locations

Based on the Water Framework Directive hydroelectric reservoirs or run-off-river power plants should not be planned in protected areas (e.g. Natura 2000 areas, nature reserves, protected river basin areas, etc. …), natural or semi-natural rivers including riparian zones as well as ecological corridors defined by national or regional network concepts.

2.1.4 Possible mitigation and compensation measures

Given that hydropower facilities are usually large-scale and require a wide area, it is difficult to mitigate their effects on biodiversity. The large-scale effects on the flooded habitat and the secondary effects of associated roads and power lines on land-use change pose a serious threat to terrestrial biodiversity. The siting of these energy facilities is a crucial factor affecting their impacts on biodiversity (Gibson et al. 2017).

Mitigation measures include the construction of upstream and downstream fish passage facilities (fish ladders, bypasses) to allow migration. In order to decrease turbine related mortality, the possibility of an intelligent turbine design or turbine shutdown on a fixed schedule could be considered.

An ecologically effective minimum flow of water as well as a bed load management are also important mitigation measures (Peters et al. 2011).

There is a variety of morphological enhancement measures like (Peters et al. 2011):

- improvement of the riverbank structure (unsealing the riverbank by removing bank structures, natural bank zoning, creation of morphological structures, removal of non-native vegetation/ planting of typical local vegetation)
- introduction of gravel banks
- introduction of disturbance elements (stones, deadwood)
- "widening of the river", development of shallow water zones
- connecting with old/lateral arms at least at medium water levels.

New technologies such as shaft power plants1 can pose viable mitigation measures, also in regard to retrofitting existing hydropower facilities. Shaft power plants allow an easier passage for fish and other aquatic wildlife as well as debris and driftwood to pass more freely downstream2. In-stream hydrokinetic turbines with vertical axis turbines (VATs) that operate freely flowing in rivers, represent another innovative but small-scale technology that simultaneously allows fish and debris to pass freely and does not modify the water discharge in river systems (Müller et al. 2023).

2.1.5 Relevance for Environmental Impact Assessment (EIA)

According to the EU's Environmental Impact Assessment (EIA) Directive dams of a certain capacity must be assessed for their impact on the environment (Environmental Impact Assessment - EIA). For further hydropower plants, it is up to individual EU Member States to decide if there will be an EIA on a case-by-case basis or by setting specific criteria (such as the location, size or type of project).

2.1.6 Summary and perspectives for the Alps

Hydropower has large environmental impacts, mostly because of habitat loss and fragmentation caused by impoundment reservoirs and associated structures. Dams or weirs interrupt the biological and morphodynamic continuity which disrupt river flows, alter sediment transport and water quality as well as block animal migration. All these changes of flowing waters and floodplains lead to negative impacts for upstream and downstream river ecosystems. For this reason, the construction of new hydropower plants must be critically evaluated. The modernization and increase of capacity at existing sites are preferable.

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[1] See https://www.tum.de/en/news-and-events/all-news/press-releases/details/36147-1

[2] See https://www.lfu.bayern.de/wasser/fischschutz_fischabstieg/ergebnisse/index.htm?cc

Hydropower is a main source of renewable energy in the Alps because it offers a flexible power generation and large amounts of energy can be generated, especially from large hydropower plants. In the context of the energy transition towards renewables and the related challenge of securing energy for peak demands, particularly pump-storage, hydropower is predicted to play an even more important role in the future. Most hydropower potential in the Alps is already realized. Remaining hydropower potentials need to be reconciled carefully, as most of the bigger rivers are already intensively used and small hydropower projects tend to impact river ecosystems to a larger extent in relation to the amount of energy generated (Hastik et al. 2016). Although the potential is already largely exhausted in most parts of the Alps, there are more projects planned: for example a large reservoir in the Swiss park Binntal (Meister 2023) or the Kaunertal/Platzertal and Kühtai projects in Tyrol.

Table 2: Synopsis Hydropower

General environmental impacts	• interruption of the biological continuity of the watercourse, physical barrier • direct damage of organisms passing the turbine plant • preventing or restricting the upstream and downstream migration of fish and invertebrates • shift from fast flowing to still water creating homogenized conditions favouring non-native species • interruption of the morphodynamic continuity of flowing waters, sediment retention causing alteration of the geomorphological features of the downstream river (erosion and incision of river channels) • impacts on downstream river ecosystems (e.g. alternation of hydrological cycles, loss of areas exposed to regular inundation • negative impacts due to access infrastructure (roads, construction areas …): removal of vegetation and habitat destruction for local fauna Additional impacts of hydroelectric reservoir (dam) • habitat loss and fragmentation caused by impoundment reservoirs (large land take) • visual impact of large dams on the landscape • increase in water temperature, degradation of water quality in the reservoir • sediment accumulation in the reservoir causing loss of storage capacity, bottom outlet obstruction, abrasion risk on intakes and hydraulic turbines • natural hazard protection, defuse extreme flood events Additional impacts of hydropeaking (discontinuous release of water to accommodate peaks of energy demand) • artificial flow and water level fluctuations downstream of the dam causing damages to the aquatic life, riparian vegetation and river morphology

Impacts on connectivity	Run-of-river power plants: • low impact on structural connectivity because of minimal land take • high impact on functional connectivity because of barrier/ fragmentation effects in the water body Hydroelectric reservoir (dam): • high impact on structural and functional connectivity because of usually large land take and barrier/ fragmentation effects
Suitable locations	• along already degraded rivers
Unsuitable locations	• protected areas (e.g. Natura 2000 areas, nature reserves, …) • natural or semi-natural rivers including riparian zones, areas designated as ecological corridors
Mitigation	• Upstream and downstream fish passage facilities (fish ladders, bypasses) to allow migration • intelligent turbine design or turbine shutdown on a fixed schedule decreasing turbine related mortality • ecologically effective minimum flow of water • bed-load management • morphological enhancement measures: ➢ improvement of the riverbank structure (unsealing the riverbank) ➢ introduction of gravel banks ➢ introduction of disturbance elements (stones, deadwood) • New hydropower technologies with less environmental impacts

2.2 Windpower: windmills

Wind power is the use of air flow through wind turbines to mechanically produce electricity. Recognized as one of the most mature renewable energy technologies, wind energy has been developing and expanding rapidly in recent years.

Figure 2: Wind Turbine

2.2.1 Environmental impacts of windmills

The amount of **land** required for wind turbine installation is comparatively small. The base of an average 3-megawatt wind turbine requires an area of 100 square metres. The entire foundation covers an area of around 300 square metres and 600 cubic metres of concrete and steel and is largely sealed (BUND & NABU 2023). However, the removal of vegetation and habitat destruction for local fauna by providing roads, construction areas and areas for material storage must not be ignored (Peters et al. 2011).

One of the greatest threats posed by wind power is turbine **collision with birds and bats**. Due to their species-specific behaviour, certain bat and bird species can be endangered by wind turbines. Potential threats arise from collisions with the rotating rotor blades and from barotrauma (usually fatal injuries to the lungs of bats caused by rapid changes in ambient pressure) (BUND & NABU 2023). However, impacts on birds and bats vary strongly, depending on site-specific factors (positioning of power station with respect to topography, winds and migration routes), species-specific factors, diurnal and seasonal factors (yearly migration movements) (Balest et al. 2015).

For the majority of bird species there is no population threat. According to a study by Grünkorn et al. 2016 for almost all bird species no threat to populations due to collisions is to be expected, even in relation to a large-scale expansion of wind energy utilisation. For some species, however, particularly the common buzzard and red kite, the results indicate that collision rates are already occurring due to the current state of expansion, which could lead to a population decline. For the red kite, "*the current expansion of wind energy utilisation does not result in a general population decline due to collisions*". With regard to the common buzzard, however, the results of the study indicate high collision rates and potentially population-impacting effects of the extent of previous wind energy utilisation. Against the background of the large population of the common buzzard in Germany, there is no acute threat to the population but at least regionally strong population declines have been documented (Deutscher Bundestag Wissenschaftliche Dienste 2019).

The death rates associated with wind turbine collisions are generally lower than other anthropogenic causes of death, such as collisions with windows or power lines, entanglement in fences, cat predation, and mortalities related to pesticide use. Nevertheless, impacts on endangered species or species with low reproduction rates may be a matter of serious concern (Balest et al. 2015).

The bird mortality rate increases in areas where turbines are located on ridges, on upwind slopes, or close to the bird migration routes. For example, if a wind farm is on a bird migratory route, birds have to avoid the wind farm and deviate from their usual route. The extra deviation work will increase the energy expenditure of the birds and reduce their survival rates. This wind farm barrier effect on birds is species-specific (Dai et al. 2015). A high bat mortality rate close to wind farms on the forested ridges has been observed (Dai et al. 2015). Studies show that tower height increases the mortality among bats especially when tower height exceeded 65 m. Bird mortality also increases with greater turbine height (Gibson et al. 2017).

Another negative impact of wind turbines on birds is **disturbance**, which includes habitat destruction, the barrier effect and impact on the bird breeding and feeding behaviour. Construction of wind turbines and associated infrastructures may cause destruction of local habitat. Construction of power lines and roads for wind farms may create other obstacles for birds (Dai et al. 2015).

Wind turbines have no **fragmenting** effect on terrestrial wildlife. Large and medium-sized mammals can apparently become quite accustomed to a wind farm. After temporarily avoiding the area during the construction phase, the habitats are utilised again. Negative consequences at population level have not been observed to date. Some mammal species can suffer permanent or temporary habitat loss due to wind farms and the accompanying infrastructure (Deutscher Bundestag Wissenschaftliche Dienste 2019).

During construction of a wind farm, some activities such as foundation excavation and road construction can lead to large-scale avoidance of an area (Dai et al. 2015). Due to disturbing human activities wildlife corridors can be interrupted. All impacts can vary greatly depending on the animal species, habitat, season, area of a wind farm and arrangement of the wind turbines. In open grasslands, for example, the consequences can be very different from those in wooded or mountainous regions, for small-scale and stationary species different from those for large-scale migratory species (Deutscher Bundestag Wissenschaftliche Dienste 2019).

Different studies have shown that wind turbines can change **weather and local climate**. A nocturnal warming of the ground temperatures of approx. 0.5 °C was observed in the region directly below the plant. This warming effect was locally limited. It was lower than the natural variability of the climate between years and the expected changes due to greenhouse gas emissions (Deutscher Bundestag Wissenschaftliche Dienste 2019).

Due to the introduction of technical structures windmills induce a **visual and aesthetic impact** on the landscape. The impact intensity of wind turbines decreases when viewed from a greater distance. It is a subjective issue: People's positive or negative attitude depend on their perception on the unity of the environment, their personal feeling towards the effects of wind turbines on the landscape, and their general attitude about the wind energy industry (Dai et al. 2015). Humans feel disturbed by the rotating wind turbines and their noise emissions as well as flicker effects (Peters et al. 2011). Surveys showed that the public usually supports wind power and the renewable energy industry. However, most residents may oppose construction of a new wind farm close to them, even though the awareness of the benefit for the society is present (Dai et al. 2015).

Noise is one of the major environmental hindrances for the development of the wind power industry. According to van den Berg 2004 people reacted strongly to the wind turbine noise in the range of 500 m and experienced annoyance in the range of 1900 m surrounding the wind farm.

According to the Federal Environment Agency (Deutscher Bundestag Wissenschaftliche Dienste 2019) the infrasound pollution caused by wind turbines is very low; it has no negative impact on human health. In general, a sound power level of 103 dB(A) can be assumed for wind turbines between 500kW and 2MW. This sound level decreases considerably depending on the distance and wind direction. At a distance of 400 metres, for example, the level can drop to 40 dB(A), depending on the wind direction. The available scientific findings indicated that electromagnetic fields, shadow flickering, low-frequency noise and infrasound from wind turbines could not affect human health (Deutscher Bundestag Wissenschaftliche Dienste 2019).

2.2.2 Suitable locations

Site selection of a wind farm is very important. As a matter of course wind farms should only be built in areas where a high energy production is expected. They should be far away from important bird habitats and bird migration routes. Spatial distribution and aggregation activities of vulnerable species should be assessed before a wind farm construction to minimize bird disturbances. In general, concentration areas should be designated to minimise impacts on landscape, habitats and wildlife as much as possible. Sufficient distances to breeding and resting places for birds should be maintained (Dai et al. 2015).

Particularly with regard to wind mills in forests, areas that are easily accessible with existing roads should be selected (BUND & NABU 2023).

2.2.3 Unsuitable locations

Areas such as ridgelines, which are high volume transit areas for flying wildlife, should be avoided whenever possible. Wind farms should not be constructed near habitats for threatened bird or bat species and important migratory routes for flying animals (Gibson et al. 2017). Areas with high perceived scenic quality, should be avoided (Dai et al. 2015).

Old, near-natural forests which are extensively managed are unsuitable for wind turbines. These forests generally provide habitats for numerous strictly protected species. Animals such as capercaillie, black stork and bats are particularly affected by interventions in the forest, as the forest is an important refuge for these species (BUND & NABU 2023).

The following areas should also be avoided (BUND & NABU 2023):

- Protected areas like Natura 2000 areas, nature reserves, core areas of national parks and biosphere reserves
- European bird protection area (under the European Union Directive on the Conservation of Wild Birds) with occurrences of wind energy-sensitive bird species
- Migration concentration corridors of birds or bats for which wind turbines can lead to a "significant increase in the risk of killing or injury" or to a considerable scaring effect
- Density centers of collision-sensitive bird species, elaborated in selected Alpine subregions (Kuth 2021)
- Resting and wintering areas for migratory birds of international and national importance

2.2.4 Possible mitigation and compensation measures

Site selection plays a crucial role in reducing negative impacts of wind turbines (see previous chapters). It is important to bundle the turbines and connect them as closely as possible to existing infrastructure. In this way, many near-natural landscapes can be kept free of technical structures (BUND & NABU 2023). To encourage residents to have a positive perception of wind farms, public participation in the early stages of the planning and implementation of wind power projects are recommended, such as working together to seek solutions to the visual impact issues (Dai et al. 2015).

Various measures, such as considering breeding sites, feeding habitats and flight paths of wind energy sensitive animals in planning and approval procedures can reduce the negative impact of wind turbines. In general, mortality rates increase with turbine height. By building wind turbines at the lowest height feasible, mortality of birds and bats can be markedly reduced, although there may be tradeoffs between having a smaller number of large turbines versus many smaller turbines (Gibson et al. 2017).

Furthermore, wind technology should be improved to reduce the noise and heat generated by turbines (Gibson et al. 2017). To reduce noise from wind turbines, improved blade design is the key. An appropriate design of blades can significantly reduce the aerodynamic noise. Structural design improvements were also effective in reducing bird mortality. Enlarging the blades and slowing the rotational speed of wind turbines can lower the bird fatality rate (Dai et al. 2015).

In order to avoid collisions switching off systems at times of increased bird or bat activity can be very effective (Automatic anti-collision systems). A wind turbine that can automatically stop when birds approach could be very effective. Results show that bird mortality decreased by 50% (Dai et al. 2015). Recently a camera detection system for birds has been developed (Lingenhöhl 2021). This system consists of an elevated camera that covers several turbines simultaneously. It recognises approaching large birds via optical sensors and compares the images with the help of artificial intelligence to identify protected species as well as their flight direction and speed. Depending on the direction in which the bird is travelling, the system switches off the turbines concerned. According to the company, the detection works over a distance of one kilometre.

For birds of prey, such as the red kite, the surroundings of the wind turbines can be designed in an unattractive way at the base of the mast (mowing only in the winter months) and in surrounding fields (no meadows and pastures). There should be sufficient distances from the birds' breeding and resting sites (BUND & NABU 2023).

Restricting construction activities to non-breeding periods could help reduce the negative effects of bird disturbance (Dai et al. 2015).

2.2.5 Relevance for Environmental Impact Assessment (EIA)

In the EU's Environmental Impact Assessment (EIA) Directive windpower is not mentioned as a subject to an obligatory Environmental Impact Assessment (EIA). However, it is up to individual EU Member States to decide if there will be an EIA on a case-by-case basis or by setting specific criteria (such as the location, size or type of project).

2.2.6 Summary and perspectives for the Alps

Environmental impacts of wind power are bird and bat mortalities caused by the wind turbines, noise induced by wind turbine operation and the visual impact of wind farms on the landscape. By selecting a suitable location and suitable design of the wind turbines, most negative impacts can be avoided or minimised when planning a wind farm.

Wind farm projects are often highly contested at local, implementation level. To encourage residents to have a positive perception of wind farms, public participation in the early stages of the planning process and in profit-sharing schemes is recommended.

There are problems with the expansion of wind power in mountainous areas (Meister 2023). Operation and maintenance of wind farms at high altitudes is limited by the lower accessibility of mountainous areas, due to their abrupt topography and insufficient access to roads and grid connections. Moreover, wind farms located at high altitudes are associated with increased visual intrusion at longer distances (Kraxner et al. 2015).

Table 3: Synopsis Windpower

General environmental impacts	• Bird and bat mortalities caused by the wind turbines • disturbance of breeding and resting birds due to rotating wind turbines, resulting in avoidance of the area and loss of habitat • local climate change: locally limited nocturnal warming of the ground temperatures of approx. 0.5 °C • negative impacts due to access infrastructure (roads, construction areas …): removal of vegetation and habitat destruction for local fauna • visual impact on the landscape as a subjective issue (disturbing people) • noise induced by wind turbine operation (disturbing people)
Impacts on connectivity	• low impact on structural connectivity because of minimal land take • partly high impact on functional connectivity because of collisions (birds, bats)
Suitable locations	Site selection is very important: • far from important bird habitats and bird migration routes and sufficient distance to breeding, mating and resting places for birds • Areas that are already well accessible with existing roads and closely connected to existing infrastructure
Unsuitable locations	• protected areas (e.g. Natura 2000 areas, nature reserves, core areas of national parks and biosphere reserves) • European bird protection areas with occurrences of wind energy-sensitive bird species • designated bird migration routes • density centers of collision-sensitive bird species • old, natural or semi-natural forests • forested ridgelines because of high collision rates of birds and bats • areas with high perceived scenic quality (landscape quality)
Mitigation	• turbine design optimization • switch off systems at times of increased bird/bat activity to prevent/avoid collisions (Automatic anti-collision systems) • unattractive design of the environment at the base of the mast and in surrounding fields for wind energy-sensitive birds (red kites)

2.3 Solar Power - Photovoltaics: Ground-mounted solar panels

Solar systems are basically divided into photovoltaic systems for the generation of solar electricity and others that generate solar heat directly as solar thermal systems and feed it into heating grids or sinks. This report focuses on solar photovoltaic (PV) in which photons from solar radiation are converted to electricity.

Photovoltaic systems are installed either on the roofs of buildings or in the form of ground-mounted systems. While the installation and use of photovoltaic systems on buildings does not lead to relevant impacts on nature and the landscape, ground-mounted systems can have a negative impact on the environment.

Ground-mounted photovoltaic modules are mounted on racks and usually orientated either to the south or east-west. For technical reasons - and increasingly also for reasons of nature conservation or agriculture - distances are maintained between the modules so that they are not covered or are only partially or temporarily shaded (Günnewig et al. 2022).

Figure 3: Ground-mounted solar panels

2.3.1 Environmental impacts of ground-mounted solar installations

The impacts of ground-mounted solar installations mainly depend on initial condition (land use, habitats and species), the compactness of the installation, its height, extent and visibility as well as by the topographical characteristics of the site and its surroundings (Günnewig et al. 2022).

The **land use** of a solar park is only associated with a small amount of new sealing of the installation site and the land is therefore not fundamentally lost for other functions and uses. Depending on the system design, different areas of the facility are covered by module surfaces, but they are still generally available as (partially shaded) green spaces with comparatively extensive use. The degree of coverage varies; usually a proportion of around 30 to 50 % coverage can be assumed. The consequences are shading or scattered light incidence, surface drying of the soil below the modules and microclimatic changes; in each case also depending on the height of the modules (Günnewig et al. 2022).

Soil is usually sealed on very small areas, e.g. through the construction of foundations, e.g. for the inverter station or storage facility, storage areas and any additional access roads and facilities (Günnewig et al. 2022). Effects on soil functions also include shielding, soil erosion, drying out of topsoil, soil densification as well as soil relocation. Positive aspects include extensive soil use compared to arable land utilisation (LABO 2023).

The current knowledge on the effects of ground-mounted solar installations on species and biotopes (including biotope networks) is still unsatisfactory. Ground-mounted solar systems lead to changes of structures within the facility (shading effects and microclimatic changes).

Converting intensively used agricultural land into Photovoltaic systems could reduce the input of pesticides, biocides, and fertilizers on this land. If they are of the appropriate quality (in terms of location, structure and maintenance), ground-mounted solar parks can contribute to biodiversity. For example, they can provide roosting, feeding or breeding habitats for bird species - at least for those species that do not require large areas of open land (Trautner et al. 2022).

Whether ground-mounted solar plants are suitable for realising the biotope network is a controversial issue. The fencing can lead to **barrier** effects for mobile land-dwelling animal species. The larger the area of a solar park, the more likely it is to act as a barrier especially for large animals. Smaller installations, on the other hand, can even act as a "stepping stone" for plants and smaller animal species. The fragmenting effect and barrier function on surrounding habitats is particularly significant in the case of large-scale facilities (from a length of approx. 500 m). In this case it is essential to plan migration corridors as crossing aids (Hietel et al. 2021). There are also edge effects (avoidance behaviour) for bird species requiring open space. Species like skylark require large areas of open land that are free of disturbance and barriers (Trautner et al. 2022).

The **visual impact** of ground-mounted solar energy systems is mainly determined by the size of the installation and the arrangement / height of the modules. On areas that have not previously been subject to construction, the ground-mounted system leads to a technical overprint on the landscape (Günnewig et al. 2022; Meister 2023).

Operational effects such as material emissions or electric and magnetic fields do not occur, or only to a very small extent. Direct current is transported between the modules and the inverter. The installed cable strands are shielded from the living environment (Günnewig et al. 2022).

Agri-photovoltaic concepts allow agricultural use and energetic solar power production to take place simultaneously on the same area. Even if such systems significantly increase the amount of land required per unit of energy generated, their advantage lies in the multiple use of land that is already burdened by intensive use (Günnewig et al. 2022). The area required to achieve comparable capacities is typically 20-40 % higher for agrivoltaic systems compared to conventional ground-mounted solar installations. Furthermore, agrivoltaics often utilise high elevated systems which have a negative impact especially on aesthetically sensitive landscapes.

"Moorland photovoltaics" focus on drained moorland soils or organic soils that are also currently used for agriculture and contribute significantly to climate change due to their high greenhouse gas emissions. However, a prerequisite for the future promotion of ground-mounted photovoltaic systems on such areas is the waterlogging (necessary increase of soil wetness), a task that has to be solved scientifically and technically. The findings to date on potential environmental impacts are limited (Günnewig et al. 2022).

In Bavaria there is also the concept of "**Solar biotope network"** ("*Solarbiotopverbund*"[3]): ground-mounted PV systems that run through the landscape as a green energy band, whose areas between the rows of modules are cultivated as extensively used grassland in the interests of species protection. Compared to coverage levels of 60-70% typical for conventional installations, installations contributing to a solar biotope network feature reduced coverage of up to 30% of the landscape. As such concepts have not yet been implemented, there is no experience of the possible effects.

2.3.2 Suitable locations

Site selection plays a key role in the evaluation of ground-mounted solar installations and their effects. Suitable locations are sites that are already degraded and lack threatened species like waste disposal or contaminated sites, landfills, post-mining areas, paved/sealed sites, along motorways, large commercial and industrial areas or intensively used agricultural land. Converting intensively used agricultural land into Photovoltaic systems could reduce the input of pesticides, biocides, and fertilizers on this land (Gibson et al. 2017; Günnewig et al. 2022).

2.3.3 Unsuitable locations

Solar installations should not be constructed in protected areas (e.g. conservation areas, water protection areas), areas of high nature conservation value, areas designated as ecological corridors (defined by national or regional network concepts) or as core and priority areas for nature conservation in the landscape plans, riparian buffer zones, floodplains, natural watercourses and lakes, soil with very high significance for natural soil functions, agricultural soil with high degree of productivity.

Areas with strictly protected species should not be designated as sites. On agricultural land, this especially applies to the occurrence of bird species requiring open space (e.g. skylarks, lapwings), but also to the known resting areas of migratory birds (Günnewig et al. 2022; Trautner et al. 2022).

[3] See https://land-gemeinsam-gestalten.bayern/projekte/172/solarbiotopverbund

2.3.4 Possible mitigation and compensation measures

Depending on the initial situation prior to the construction of the system, a solar parc can be designed in such a way that its location can continue to fulfil functions for the ecosystem and may even have positive effects compared to the initial situation.

A landscape-oriented design of the facility supports the visual integration into the environment: There should be a suitable arrangement of the solar panels. For example the modules could form a green energy band, relatively loosely arranged and integrated into a mosaic of extensively used grassland and shrubs and trees ("Solar biotope network").

In order to minimise the fragmentation effect, fencing of the facility should be avoided or at least permeable at the bottom for small and medium-sized mammals (15 cm distance between the fence and the ground). If installations exceed a length of 500 m, crossing aids or migration corridors for large mammals are recommended. The migration corridors should be at least 20 meters wide, and significantly wider in the case of large mammal migration routes. The solar parc can also be divided into several sub-areas (Hietel et al. 2021).

The development and maintenance of extensive use, species- and flower-rich grassland within a solar parc can improve previously intensively used agricultural areas. The following mitigation measures should be implemented:

- Sufficiently large (wide) open spaces between the rows of solar panels, Sunlit strips at least 3 m wide between the rows of modules
- Module distance to the ground at least 0.8 m
- Greening of the plant area using seeds from local species or locally obtained mown material,
- no fertilization,
- no use of pesticides,
- up to 2 mowing intervals (use of insect-friendly mower, cutting height 10 cm) with removal of mowed material or/and site-adapted grazing or/and no mulching

The provision of structures and differentiated maintenance adapted to the requirements of species can enhance the value of open spaces in solar installations. For suitability as breeding habitat in general, sufficiently large open spaces between the modules or at the edge of the installation appear to play an important role. Additional habitats can be created for structure-tolerant or structure-loving species, especially when realised on previously intensively used arable land (Trautner et al. 2022).

To minimise the impact of linking photovoltaic systems to the electricity grid, preference should be given to sites that are close to consumers, grid feed-in points, transformer stations, etc. This aspect is considered in spatial planning (Günnewig et al. 2022).

In order to reduce land use, compensation measures should be implemented directly within the solar farm.

2.3.5 Relevance for Environmental Impact Assessment (EIA)

In the EU's Environmental Impact Assessment (EIA) Directive solar power is not mentioned as a subject to an obligatory Environmental Impact Assessment (EIA). However, it is up to individual EU Member States to decide if there will be an EIA on a case-by-case basis or by setting specific criteria (such as the location, size or type of project).

2.3.6 Summary and perspectives for the Alps

Impacts associated with ground mounted photovoltaic systems strongly depend on former land uses. Impacts might be positive in the case of agricultural extensification in impoverished agricultural landscapes while negative impacts are likely to occur in ecologically sensitive areas, particularly visual impacts and fragmentation of habitats.

Because of increasing energy demand, further PV systems on open spaces are expected especially in the Alps, given the high radiation, low temperatures and albedo effect that positively affect the efficiency of photovoltaic systems compared to lowland conditions. The theoretical potential in the Alps from PV plants is the most important in comparison with the other three renewable technologies (bioenergy, windpower, hydropower) (Kraxner et al. 2015). There are large projects already planned for higher altitude areas in the alpine mountains (Meister 2023). Solar plants have comparatively low impact on the ecosystem if ecologically important sites and forest areas are avoided (Kraxner et al. 2015). However, there are some fears that extensively used areas in the alpine region will be used for the construction of solar parks (Meister 2023).

Table 4: Synopsis Photovoltaics: Ground-mounted solar systems

General environmental impacts	Impacts mainly depend on the selected location and the design of the solar park: • land use of the facility, soil sealing, loss of soil functions • habitat loss due to land use • shading effects and microclimatic changes • fencing as a functional (partial) barrier • edge effects (avoidance behaviour) for bird species requiring open space • negative impacts due to access infrastructure (roads, construction areas …): removal of vegetation and habitat destruction for local fauna • visual impact: negative effect on the landscape aesthetics (disturbing people)
Impacts on connectivity	• mostly low impact on structural and functional connectivity because of usually low soil sealing and marginal barrier effects. Effects depend on the area size and design! • large area photovoltaics: high impact due to extensive habitat changes (structural connectivity) and to fragmenting effects if fenced (functional connectivity). Above a length of 500 metres, fragmenting effects on large mammals are to be expected.

Suitable locations	sites that are already degraded and lack threatened species: • waste disposal or contaminated sites, landfills, post-mining areas • paved/sealed sites • along motorways • large commercial and industrial areas • intensively used agricultural land
Unsuitable locations	• protected areas (e.g. Nature 2000 areas, nature reserves, water protection areas) • areas of high nature conservation value, areas designated as ecological corridors • riparian buffer zones, floodplains • natural watercourses and lakes • soil with very high significance for natural soil functions • agricultural soil with high degree of productivity
Mitigation	• landscape-oriented design of the facility, visual integration into the environment: suitable arrangement of the solar panels (e.g. “Solar biotope network”) • sufficiently large (wide) open spaces between the rows of solar panels (sunlit strips at least 3 m wide between the rows) • elevation of the solar panels (panel distance to the ground at least 0.8 m) • no fencing or at least permeable for small and medium-sized mammals (15 cm distance between the fence and the ground), migration corridors as crossing aids for large-scale facilities • development and maintenance of extensively used, species- and flower-rich grassland in the solar park ➢ using seeds from local species or locally obtained mown material ➢ no fertilization, no use of pesticides ➢ up to 2 mowing intervals (use of insect-friendly mower, cutting height 10 cm) with removal of mowed material or/and site-adapted grazing ➢ no mulching

2.4 Bioenergy – Biomass

Biomass for energy (bioenergy) continues to be the main source of renewable energy in the EU and accounted for about 59% of the renewable energy consumption in 2021, according to the Commission report on bioenergy sustainability, published as part of the State of the energy union report 2023. (https://energy.ec.europa.eu/news/bioenergy-report-outlines-progress-being-made-across-eu-2023-10-27_en)

The term 'bioenergy' covers a wide variety of raw materials, technology paths and areas of application. According to the European Commission biomass originates from organic material from forestry and agriculture (such as trees and plants), from waste and residues of biological origin as well as the biodegradable fraction of waste. (https://energy.ec.europa.eu/topics/renewable-energy/bioenergy/biomass_en)

The raw materials can be of regional origin or reach us via global trade flows. Bioenergy can be made available in gaseous form as biogas or biomethane. It can also be used in liquid form, for example as pure vegetable oil for combined heat and power plants or as biofuel. It is also available in solid form, for example as logs, wood chips and pellets or straw pellets. The variety of raw materials and conversion techniques allows bioenergy to be used in all energy-relevant sectors: It can be used for heating, electricity generation, and the production of transport fuels. (https://www.umweltbundesamt.de/themen/klima-energie/erneuerbare-energien/bioenergie#bioenergie-ein-weites-und-komplexes-feld-)

Biomass energy seems to be a sustainable option. "It has proved to be so for thousands of years, but only as long as it is used to a very limited extent. The picture begins to change once the likely impacts of biomass energy generation and utilization on the large scale presently envisaged are considered" (Abbasi & Abbasi 2010).

Unlike hydropower, wind and solar, generating power from biomass emits greenhouse gases (carbon dioxide). Because of the renewable nature of biomass, it is considered as a carbon-neutral electricity source. Biomass sources, such as crops and trees, capture carbon dioxide during photosynthesis and sequester it. The carbon cycle remains in balance if trees and other plants absorb as much carbon dioxide as they emit during biomass combustion. However, the carbon impact of bioenergy depends on the combustion technology, how the biomass is harvested, any regrowing efforts, the type of biomass used, timing, and the energy resource it's replacing. For example, consider electricity from woody biomass: burning wood to produce electricity emits carbon dioxide into the atmosphere, but trees will regrow and capture the emitted carbon dioxide. However, forests can take decades to regrow and sequester carbon, so the carbon neutrality of that source of bioenergy depends on the time frame. If companies burn trees at a faster rate than they're being replanted and grown or burn trees that would otherwise be left untouched in a forest, carbon neutrality is compromised.

Figure 4: Biogas plant

2.4.1 Environmental impacts of Bioenergy

In terms of environmental impact, a distinction must be made between the energy plant itself (producing bioenergy) and the land-use changes associated with the cultivation and extraction of biomass.

The most important bioenergy technologies include combustion, anaerobic digestion, gasification, pyrolysis and hydrothermal liquefaction. Due to this wide range of technologies, there are quite different environmental impacts. The potential impacts associated with the physical construction and infrastructure needs of bioenergy plants and the processing biomass for energy (e.g. pellet mills, sawmills, storage facilities for biomass for energy) are comparable to that of other industrial plants of a similar size:

- land use of the facility, soil sealing
- habitat loss due to land use (destruction of vegetation)
- fragmentation of habitats (depending on the size of the facility)
- air pollution
- noise pollution due to operating noise and substrate delivery traffic
- visual impact: negative effect on the landscape due to the building structures

The specific impacts of plants for biomass combustion and biogas production are described below.

Biomass combustion

Biomass burning is the most important form of renewable energy ever used. Modern biomass combustion offers technologically mature solutions across the whole capacity range, from small-scale residential applications with several kilowatts of electricity output to large power plants and combined heat and power plants outputting hundreds of megawatts. Similar to the capacity, the range of fuels is also broad. While woody biomass is still by far the most important biomass fuel, biogenic residues from agriculture, industry, or municipalities are also used in combustion technologies (Bacovsky et al. 2022).

During biomass combustion, gaseous pollutants (carbon dioxide, carbon monoxide, nitrogen oxides, sulfur oxides) and particulate pollutants are generated that can lead to adverse impacts on humans and habitats. Wood-burning systems for example produce comparatively high levels of particulate matter and other air pollutants, such as organic compounds from incomplete combustion. These also include polycyclic aromatic hydrocarbons. Mitigation strategies have, however, been developed and implemented, like low-emission wood-burning systems, leading to significant emission reductions (Bacovsky et al. 2022).

Anaerobic digestion (Biogas production)

Biogas production, also called anaerobic digestion, is a biotechnological process through which a mixed microbial culture is broken down in the absence of oxygen. As the organic matter (proteins, carbohydrates, fats) degrades, it is converted to intermediates (hydrogen, volatile fatty acids, alcohols, etc.) and finally to biogas. The biogas produced consists mainly of methane and carbon dioxide, together with small amounts of hydrogen, hydrogen sulphide, ammonia, and water. Biogas can be used locally for heating or for combined heat and power production (Bacovsky et al. 2022).

Biogas is largely produced from different types of residues and by-products: biodegradable wastes (e.g., organic fraction from municipal solid waste), industrial by-products/wastes (e.g., food and beverage industry), agricultural by-products (manure, straw), and wastewater (sewage sludge, industrial wastewaters). In some specific countries, biogas is produced from purposely grown biomass feedstock, for example maize, which allow an additional crop to be harvested on an agricultural cultivation area (Bacovsky et al. 2022).

After the anaerobic digestion process, undegradable biomass, nutrients, and water remain as the non-gaseous by-products. This fermentation residues (“digestates”), either liquid or solid, are utilised as fertilisers and applied on land in a circular economy approach. To enable this, the digestate has to meet certain quality requirements (regarding e.g., heavy metal content), which are mainly influenced by the feedstock quality (Bacovsky et al. 2022).

Biogas plants are complex systems with considerable hazard potential. This is because large quantities of extremely flammable and climate-damaging gases are produced, stored and converted in biogas plants. Biogas plants also contain considerable volumes of substances that are generally hazardous to water in the form of liquid manure, substrates or fermentation residues.

The cultivation of biomass for energy use has an impact on nature and the landscape. As land is a limited resource, the increasing use of bioenergy can result in changes of land management and land use, both directly and indirectly (Bacovsky et al. 2022):

- Direct land use change refers to the direct conversion of a specific land area from one use (e.g., forest, agricultural crop cultivation for food/feed) to another (e.g., crop cultivation for biofuels).
- Indirect land use change is an unintended consequence of a land use decision taken elsewhere. Bioenergy production that uses feedstocks grown on arable and pasture land can cause indirect land use change via market mechanisms. For instance, increased demand for food and feed will result in increased crop prices. This incentivises the conversion of additional land to agricultural use. Converting land with high natural carbon stocks to agricultural use can lead to significant greenhouse gas emissions.

Some agricultural and forest practices have positive or negative impacts on biodiversity. It depends to a large extent on their scale and context, in particular on the intensity of the biomass production and on the type of affected habitat. The effects can only be described in general terms.

As the management of conventional crops is the same whether it is produced for food or for bioenergy, the impacts are neutral if there are no changes in crop type. However, increasing demand for bioenergy feedstocks is known to be leading to changes in crop type in some areas. This is mainly leading to a switch from cereals to oilseed rape or maize and this undoubtedly has detrimental impacts on a wide range of species (Bowyer et al. 2020).

Other negative impacts of the use of agricultural land on biodiversity are

- intensification of grassland management (higher fertiliser and pesticide use),
- conversion of grassland or other semi-natural habitats to bioenergy feed crop or
- afforestation of grassland or other semi-natural habitats.

Forestry practices associated with the production of biomass for bioenergy feedstocks are similar to those undertaken for timber etc. Although the impact of such practices varies according to forest type and species, they show a general pattern of increasing detrimental impacts on biodiversity as the intensity of forest management increases. Primary or old-growth forests as well as special types of forests (e.g. old beech forests) should not used for biomass production (Ewald et al. 2017). Biodiversity impacts are difficult to assess as some species might benefit from altered forest structures while the habitat for others deteriorates. In general, intensified forest management can lead to

- clear cutting of trees,
- harvesting forests more frequently (reducing rotation age and the share of old trees),

- harvesting forest that would otherwise not be harvested
- removal of dead wood,
- stump removal and whole-tree harvesting,
- tree planting and the use of pesticides and fertilisers and
- plantation forestry with dominance of non-native or non-site typical tree species (Bowyer et al. 2020).

These forestry practices destroy habitats and result in the loss of the majority of associated species (Bowyer et al. 2020).

According to Abbasi & Abbasi 2010 biomass may be “carbon neutral”, but it isn’t “nutrient neutral”. The soil conditions play an important role in the production of biomass. Biomass not only contains carbohydrates but also nutrients. Some of these nutrients will be extracted from the soil during biomass production, and some will be lost during the further processing of the biomass (Bacovsky et al. 2022). Climate change is exacerbating the loss of humus soil especially in the Alps. This means that a sustainable forest management in mountain forests is very important (Prietzel & Christophel 2013). Biomass energy production also requires large amounts of water.

2.4.2 Suitable locations

Suitable locations for bioenergy plants are sites that are already degraded and are of no particular value from a nature conservation perspective, e.g. intensively used agricultural land. Due to the necessary transport accessibility (delivery traffic), it is favourable to build energy plants in the vicinity of settlements or close to existing roads. Biogas plants are usually built directly adjacent to farms.

2.4.3 Unsuitable locations

Bioenergy plants should be far away from protected areas (e.g. Nature 2000 areas, nature reserves, water protection areas) as well as biodiversity hot spots, and ecological corridors defined by national or regional network concepts.

2.4.4 Possible mitigation and compensation measures

As already mentioned in chapter 2.4.1, there are very different energy generation systems due to the wide range of technologies. Therefore, no specific mitigation measures for bioenergy plants can be identified.

In terms of land use changes due to the cultivation of biomass the general requirements for sustainable agriculture and forestry should be applied as mitigation measures. Bioenergy feedstock production from agriculture and forestry needs sufficient and sustainable water and nutrient supplies as well as appropriate management (Bacovsky et al. 2022).

2.4.1 Relevance for Environmental Impact Assessment (EIA)

In the EU's Environmental Impact Assessment (EIA) Directive bioenergy plants are not mentioned as a subject to an obligatory Environmental Impact Assessment (EIA). However, it is up to individual EU Member States to decide if there will be an EIA on a case-by-case basis or by setting specific criteria (such as the location, size or type of project).

2.4.2 Summary and perspectives for the Alps

Land is a limited resource and has to be managed sustainably, including soils and water reserves as well as biodiversity. Creating a huge demand for biomass feedstocks may lead to overexploitation of ecosystems or to land use change, with negative consequences for biodiversity and the soil carbon and nutrient stock (Bacovsky et al. 2022). Intensification of agriculture and forestry or the conversion of natural ecosystems into energy-crop plantations will result in the loss of habitats and wildlife.

For biomass to be effective at reducing greenhouse gas emissions, it must be produced in a sustainable way. Biomass production involves a chain of activities ranging from the growing of feedstock to final energy conversion. Each step along the way can pose different sustainability challenges that need to be managed. (https://energy.ec.europa.eu/topics/renewable-energy/bioenergy/biomass_en)

In respect to bioenergy, the "provisional agreement to reinforce the EU Renewable Energy Directive" strengthens the bioenergy sustainability criteria by extending their applicability to smaller installations equal or above 7.5 MW. The agreement includes provisions to ensure that forest biomass is not sourced from certain areas with a particular importance from a biodiversity and carbon stock perspective.

The trend for biomass is declining in parts of the Alps, even though this energy source is still used in some regions (Meister 2023). The use of wood in particular appears to be a source of conflict in certain regions of the Alpes. The potential for conflict lies less in the plants than in competing interests and the demand for sustainable forest utilisation. With the expected future demand for renewable energies such conflicts will almost certainly increase (Volken et al. 2011).

Table 5: Synopsis Bioenergy

General environmental impacts	Bioenergy plant: • land use of the facility, soil sealing • habitat loss due to land use • fragmentation of habitats (depending on the size of the facility) • air pollution (gaseous and particulate pollutants) • noise pollution due to operating noise and substrate delivery traffic • spreading of fermentation residues into the environment • visual impact on the landscape due to the building structures Change of land management and land use: • loss/ degradation of habitats for plants and animals due to intensification of the utilisation of arable land, grassland and forest • loss of habitats and wildlife due to the conversion of natural ecosystems into energy-crop plantations (loss of fallow land) • negative effects on the water balance and nutrient availability in the soil due to energy crop cultivation with high water requirements
Impacts on connectivity	Bioenergy plants: • Mostly low impact on structural and functional connectivity because of usually low land take and marginal barrier effects. Effects depend on the area size of the facility! Change of land management and land use: • no general statements possible because effects depend on the area size, location and the intensity of the biomass production!
Suitable locations	• Bioenergy plants: • sites that are already degraded and lack threatened species like intensively used agricultural land • areas with good transport accessibility (e.g. settlements, close to existing roads, adjacent to farms)
Unsuitable locations	Bioenergy plants: • protected areas (e.g. Nature 2000 areas, nature reserves, core areas of biosphere reserves, water protection areas) • areas of high nature conservation value, areas designated as ecological corridors
Mitigation	-

2.5 Transmission of electricity - High voltage transmission line

The growth of energy consumption demands a large expansion of transmission line networks. Transmission lines are power lines used to move electricity from a generating site (e.g., a power plant) to an electrical substation, which often transforms the voltage from high to low before reaching consumers. Transmission lines (high voltage) differ from distribution lines (low voltage) by supporting higher voltages (from 69 kV to 800 kV), and usually extending for longer distances (Biasotto & Kindel 2018).

Transmission lines are usually built as overhead powerlines, not as underground cable. This report focuses only on overhead powerlines.

A transmission line consists of pylons and wires (energized conducters and ground wire). The dimensions depend on the type of pylons. Pylons are usually between 40 and 70 m high or taller. The crossarm width is approximately 20 to 50 m (Picture 6). The distances between the pylons are on average between 300 and 450 metres (in special cases up to 700 m.)

Figure 5: 380 kV-Transmission Line

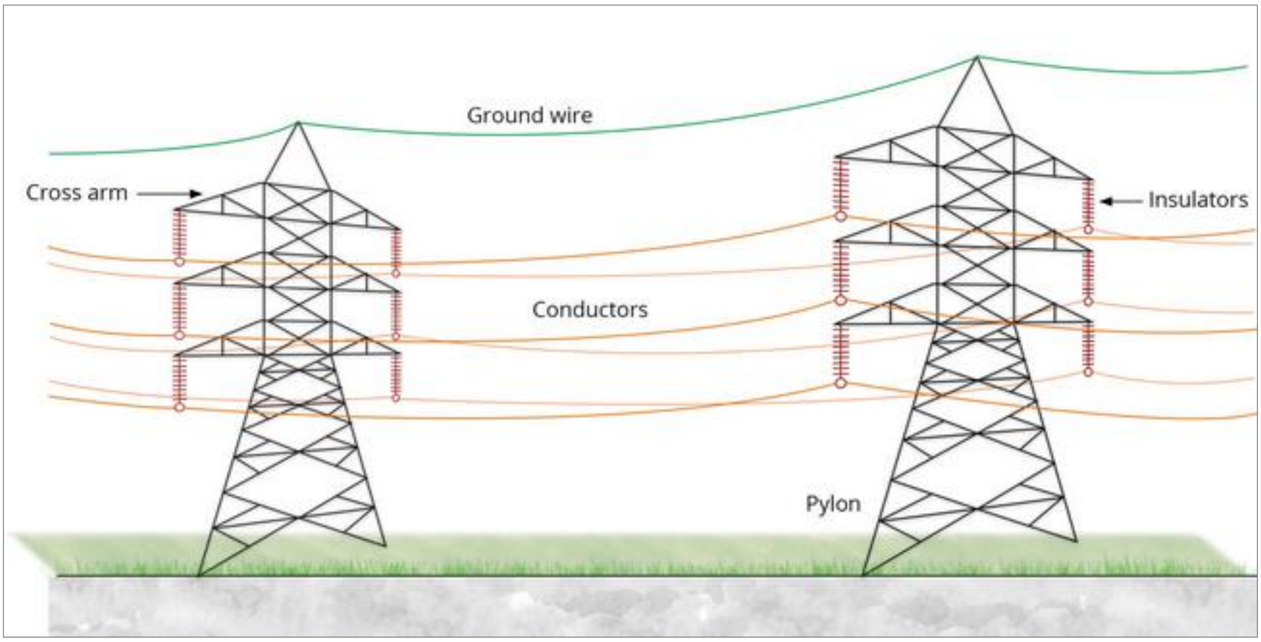

Figure 6: Parts of high-voltage transmission powerlines, showing the position of ground wires

Source: https://www.biodiversityinfrastructure.org/handbook/5-solutions/5-10-measures-to-reduce-impacts-in-other-transport-modes/5-10-2-powerlines/

2.5.1 Environmental impacts of high voltage transmission line

In terms of **land use**, a distinction must be made between the pylon sites and the area below the cables, the so called right-of-way. The area taken up permanently by the pylons is rather small. The base of a pylon is a square of about 100 and 300 m² causing only marginal loss of vegetation. The area of the right-of-way, in contrast, is relatively large. The width of the right-of-way is based on the height and spacing of the pylons and the resulting maximum swing-out behaviour of the conductor cables, plus a safety distance. A typical 110 kV overhead line with two systems usually requires a right-of-way of approximately 30 to 50 metres, being wider for lines with higher voltages. In open land, the vegetation within the right-of-way can be preserved. However, the construction of a transmission line in a forest generally involves clear-cutting in the right-of-way. This will result in a loss of previous habitats for plants and animals.

Vegetation clearing in the right-of-way can permanently lead to **soil degradation and hydrological alterations** (Biasotto & Kindel 2018), e.g. erosion, increased water runoff or change in the quality of groundwater and surface water (increased nitrate pollution) due to clear-cutting.

Bird collisions with transmission lines occur when a flying bird hits the suspended wires. Transmission lines are typically constructed with relatively thin overhead ground wires (also known as earth wires or shield wires) at the top and thicker energized conductors below (Figure 6). Birds adjust flight altitudes upward to avoid large-diameter energized wires and then collide with smaller, less visible overhead shield wires sara (Dwyer et al. 2018). Most of the collisions happen at night or in low-visibility conditions (e.g., in adverse weather conditions), when obstacles are less visible to birds.

Collision risk varies as a function of avian species and populations in the area of a given line, the surrounding habitat, and the line design. Among birds, factors affecting collision risk include size, maneuverability and flocking behaviour (Dwyer et al. 2018).

When assessing the collision risk, it is important to distinguish between breeding and resting birds. Breeding birds can become accustomed to overhead power lines in their environment. Migratory and resting birds do not recognise local barriers. Large birds (especially storks, cranes and herons), waterfowl (swans, geese, ducks, divers, mergansers and rails), waders and snipe, grouse, gulls and terns as well as nocturnally migrating songbirds and pigeons, thrushes and starlings in flocks are particularly at risk of collision (BUND & NABU 2017).

The risk of collision with a specific powerline installation depends on several aspects, like the design and features of the lines, the species of birds, the landscape and habitats in the surroundings. Birds very frequently collide with power lines near large bodies of water and reservoirs as well as lowlands, which the animals visit on their migration and use as moulting and wintering areas. Transmission lines bisecting daily movement corridors, such as those located between roosting and foraging sites, also have been most associated with avian collisions. In contrast, in cultivated landscapes without large bodies of standing water and rivers and in wooded landscapes, only a small number of bird collisions are observed (exception: forests with the presence of species with an increased risk of collision such as black stork, eagle owl, grouse or woodcock) (Bernshausen et al. 2007; Bernshausen et al. 2014; BUND & NABU 2017).

In principle, the higher the importance of the affected area for bird conservation and the higher the number of individuals of species at risk of collision, the higher the potential for conflict (BUND & NABU 2017).

With an impact range of 1 km, all adverse effects on bird species can generally be taken into account, as the foraging flights of most species take place within this radius (central home range according to Bernotat & Dierschke 2021. An effective range of up to 6 km is only considered for large birds which are vulnerable to collision and have a large home range (e.g. black stork, white-tailed eagle, osprey).

For other groups of flying animals, collisions with the wires are not known and can therefore be excluded. This also applies to bats, for which collisions with overhead lines do not generally pose a risk due to their ultrasonic localisation.

Electrocution can occur when a bird simultaneously contacts two differently energized conductors or an energized conductor and a path to ground. Electrocution is limited mostly to distribution lines (<69 kV) (Dwyer et al. 2018) and will not be considered further here.

In addition to mortality, overhead power lines regularly cause **barrier and fragmentation effects**. The construction of overhead power lines results in the creation of vertical structures which can represent a barrier. Individuals may respond to the presence of such barriers by changing their behaviour, for example, by **avoiding** to cross landscape portions where there is a power line (Biasotto & Kindel 2018).

Bird species of open land (e.g. skylark, lapwing, snipe and geese) are particularly sensitive to the scenery effects caused by vertical structures (Bernotat & Dierschke 2021). This disruptive effect and the increased risk of predation can lead to avoidance of areas close to the line, which can indirectly result in the permanent degradation or loss of bird habitats. Skylarks, for example, keep a distance of at least 100 metres from all vertical structures during the breeding season (BUND & NABU 2017).

Depending on the habitat and the species concerned, an additional threat may arise if raptors and corvids are offered perches by new pylons or power lines, thus increasing the pressure from predators (BUND & NABU 2017).

In addition to fragmentation and barrier effects, constructing a transmission line alters the habitat creating a new corridor. Such **habitat transformations and corridor effects** can have positive and negative impacts on biodiversity.

In the right-of-way (the zone below the cables) vegetation is cleared and managed to avoid interference and risk to line structures and/or to energy transmission (Biasotto & Kindel 2018). The necessary distances between the conductor cables and the vegetation are realised by means of “growth restrictions”. No taller trees can be permitted in the long term. The extent of the measures depends on the existing vegetation and the expected medium-term growth of the trees and shrubs.

This means that in forested areas in particular, the construction of overhead lines causes major disruption which in turn can lead to the fragmentation of populations (BUND & NABU 2017). Effects caused by vegetation clearing during the construction phase and later during the maintenance of the right-of-way usually result in the intensification of microclimatic gradients and change in biotic components. Thus, forest openings for power lines may reduce the habitat available for forest interior species (Biasotto & Kindel 2018).

Another result from the creation of new habitats by the transmission lines is the colonization by invasive species of plants (Biasotto & Kindel 2018).

Depending on the methods used for the right-of-way maintenance, there is a potential for increasing biological diversity. Habitat conversion can provide opportunities for uncommon plant communities to become established, providing habitat for associated organisms too. For example, forest clearing for power lines modifies the thermal regimes increasing the availability of potential nest sites and widening the habitat of a lizard species (Biasotto & Kindel 2018). Besides creating new habitats, the right-of-way can increase home range area and habitat for some species. According to King et al. (2009) forest edges created by vegetation clearing affected positively some endangered bird species from initial successional stages that use edges as nesting habitats (Biasotto & Kindel 2018).

The right-of-way of a transmission line may function as a wildlife corridor connecting areas of habitat. Smith et al. (2008) found that large carnivores exhibited a strong preference to move through the right-of-way (Biasotto & Kindel 2018).

Structures that constitute transmission lines, such as cables and pylons, can also be used as a resource by species for perching, nesting or roosting. A few studies documented that some bird species, including endangered species, use towers for nesting and as foraging perch (Biasotto & Kindel 2018). Some bird species regularly build their nests on electricity pylons, such as crows, ospreys and ravens (BUND & NABU 2017).

A transmission line is a physical obstacle in the landscape. Its **visual impact** is mainly determined by the size of the pylons. The conductor cables are usually less noticeable.

Overhead power lines generate permanent, low-frequency alternating **electric and magnetic fields** with a frequency of approximately 50 Hertz (Hz) due to the energised and current-carrying conductor cables. The legally specified threshold values for magnetic and electric fields are generally already met below the power line. This does not result in any adverse effects on human health. The impacts of electromagnetic waves on animals are still uncertain (Biasotto & Kindel 2018).

Energy discharges can produce the corona **noise**, resulting in clicks or pulses of noise. The observance of minimum distances between residential buildings and a new power line (in most cases 50 to 100 metres) avoids adverse effects on human health. The resulting impacts of noise effects on animals are still understudied (Biasotto & Kindel 2018).

2.5.2 Suitable locations

Landscapes without special protection, i.e. open agricultural landscapes or forests of low nature conservation importance (intensively used forests, monocultures) appear suitable for transmission lines.

They should be far away from important bird habitats and bird migration routes.

2.5.3 Unsuitable locations

Because a main impact of transmission lines is avian collision mortality, areas with the occurrence of collision-sensitive bird species should be avoided, particularly European bird protection areas (Important Bird Areas (IBAs) or Special Protection Areas (SPAs)), wetlands of international importance according to the Ramsar Convention, designated bird migration routes as well as larger bodies of water and reservoirs.

With regard to the landscape, the following areas should be avoided wherever possible: UNESCO World Heritage Sites, Landscape conservation areas or priority areas for tourism.

The following areas are also unsuitable: Natura 2000 areas (depending on the purpose of protection and conservation objectives), national parks, nature reserves, core zones of biosphere reserves, old natural or semi-natural forests, water protection areas of zones I and II. Transmission poles should not be constructed in waterways or banks of waterways.

2.5.4 Possible mitigation and compensation measures

The top priority is to **bundle** a planned grid expansion project with existing linear infrastructure facilities (e.g. existing lines, roads or railway tracks). Ideally, two existing power lines can be brought together on one pylon, thereby avoiding the need for planned new construction (BUND & NABU 2017).

An appropriate route alignment is a mitigation measure during the planning process of a transmission line. Powerlines should not be planned in areas relevant for birds, especially across migratory routes.

The selected **pylon shape** also influences the fragmentation effect of an overhead line. While wider single-level pylons (only one cross arm) lead to a lower risk of collision for birds due to their better visibility, the width of the necessary forest aisles can be reduced by using higher and narrower “barrel pylons” (mostly with 3 cross arms) when crossing forest areas. Fragmentation of forests can be prevented by **spanning above the canopy** (BUND & NABU 2017).

Collisions involving birds can be mitigated by **marking transmission lines** to increase their prominence to approaching birds so lines can be avoided (Dwyer et al. 2018). Bird protection markers are clearly visible and movable markers with high contrast. They are attached to the ground wire and are intended to make these thin ropes in particular more visible to birds. Studies show that the number of collision victims decreases significantly after the installation of bird protection markers (BUND & NABU 2017). Bernshausen et al. 2014 report a reduction in the risk of collision of over 90 per cent. New models are currently being tested that are also visible at dusk due to their fluorescent effect (BUND & NABU 2017).

In forested areas, it is recommended that the height of the powerline is kept lower than the height of the canopy.

Ecological rights-of-way vegetation management techniques employed below and around powerlines can play a very important role in maintaining and improving habitat for wildlife (Dwyer et al. 2018). Woody vegetation under overhead power lines is usually cleared at regular intervals and the areas are mulched. The core idea of ecological rights-of-way vegetation management is to avoid regular intensive maintenance. Instead, the areas below the power lines can be restored in several different ways according to the features of surrounding landscapes. New habitats should be developed which promotes biodiversity (Rosell et al. 2024b), for example:

- establishing meadows, maintained by grazing mammals, which can help the recovery of open habitat species, especially in some European areas where forests are expanding
- creating and connecting heathland and nutrient-poor grassland habitats that are important for species in dry and warm locations (Figure 7)

- creating a gradient of vegetation height and complexity that maintains a low risk of power disruption but increases biodiversity benefits (development of stepped, species-rich forest edges)
- creating stepping-stones along powerlines. These stepping-stones can be created in different ways, such as planting native vegetation of interest to wildlife, building ponds or providing refuge shelter for small fauna (e.g., stone rows)
- creating patches of bare ground or leaving deadwood in place to increase the diversity of habitat structures

Grazing appears to be a good technique for both limiting tree growth and contributing to the spread of species (transport of plant seeds and smaller animals in the wool over longer distances) (BUND & NABU 2017).

Figure 7: Example for heathland vegetation in the right-of-way of a 380 kV-transmission line

Figure 8 shows management alternatives to increase biodiversity in the right-of-way of powerlines.

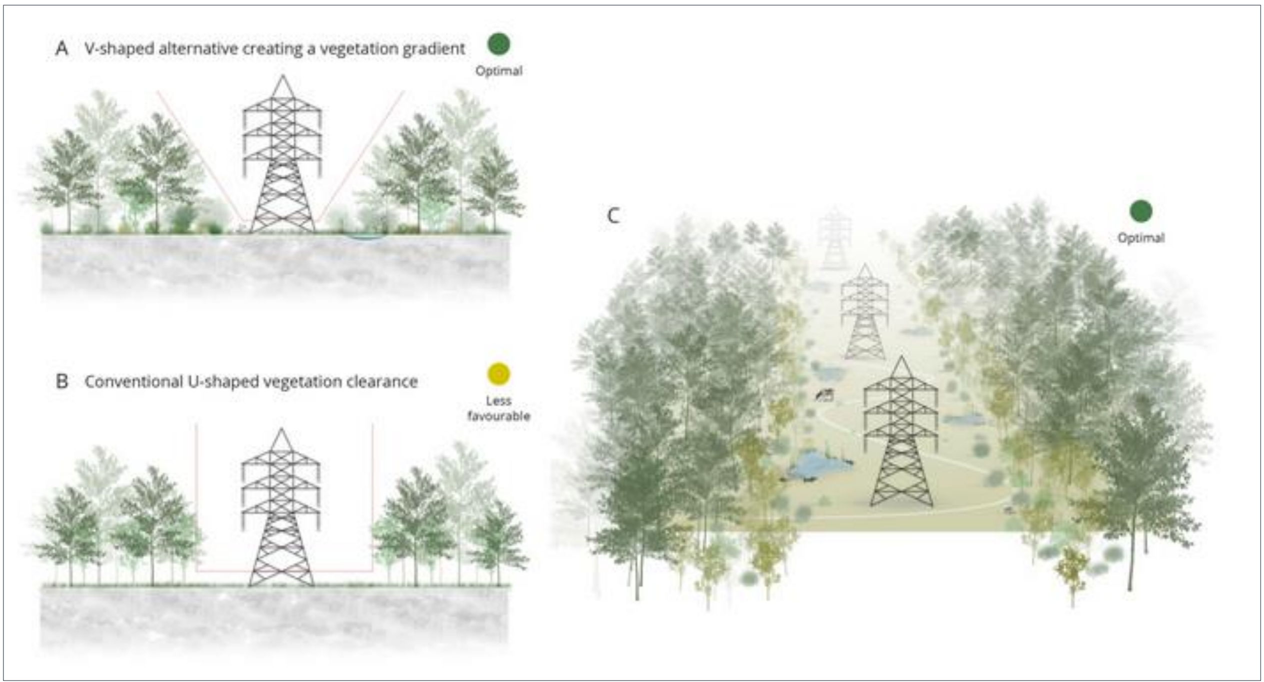

Figure 8: Management alternatives in the right-of-way in forests

A: V-shaped alternative creating a vegetation gradient; B: conventional U-shaped vegetation clearance; C: stepping-stone corridor, providing different types of habitats along the powerline corridor

Source: https://www.biodiversityinfrastructure.org/handbook/5-solutions/5-7-habitat-related-to-transport-infrastructure-hti-management/5-7-1-verges-and-other-green-areas/

2.5.5 Relevance for Environmental Impact Assessment (EIA)

In the EU's Environmental Impact Assessment (EIA) Directive transmission lines are not mentioned as a subject of an obligatory Environmental Impact Assessment (EIA). However, it is up to individual EU Member States to decide if there will be an EIA on a case-by-case basis or by setting specific criteria (such as the location, size or type of project).

2.5.6 Summary and perspectives for the Alps

Transmission lines have a significant visual impact on landscapes and transform natural habitats, creating a barrier effect for some animal species. On the other hand, they can also provide benefits for biodiversity, such as providing new habitats and ecological corridors.

In the Alps, the production of renewable energy will play a more and more important role (Meister 2023). This will inevitably lead to an increase in the number of high-voltage power lines.

Table 6: Synopsis Transmission lines

General environmental impacts	• loss/ degradation of habitats for plants and animals, mainly in forests due to vegetation clearing in the right-of-way • soil degradation and hydrological alterations, mainly in forests due to vegetation clearing in the right-of-way • bird mortalities caused by collision with the overhead line • barrier and fragmentation effects: avoidance behaviour for bird species requiring open space • habitat transformation and corridor effects (negative and positive) • electromagnetic fields • visual impact on the landscape
Impacts on connectivity	• low impact on structural connectivity because of minimal land take outside of forests • partly high impact on functional connectivity because of collisions (birds)
Suitable locations	• open agricultural landscapes • forests of low nature conservation importance (intensively used forests, monocultures) • far from important bird habitats and bird migration routes
Unsuitable locations	• European bird protection areas (Important Bird Areas (IBAs) or Special Protection Areas (SPAs)) • wetlands of international importance according to the Ramsar Convention • designated bird migration routes • near large bodies of water and reservoirs • protected areas specifically for landscape (UNESCO World Heritage Sites, Landscape conservation areas, priority areas for tourism) • other protected areas (e.g. Natura 2000 areas, nature reserves, core areas of UNCESCO Biosphere Reserves) • old natural or semi-natural forests • water protection areas of zones I and II (no construction of transmission poles in waterways or banks of waterways
Mitigation	• bundling of linear infrastructure, appropriate route alignment • appropriate design of the pylons to reduce fragmentation including spanning above the forest canopy • marking transmission lines to reduce bird collision risk

	• ecological rights-of-way vegetation management creating and connecting new habitats

2.6 Roads/ highways

In addition to the roadway itself, the possible project components include e.g. embankments, cut slopes, safety strips, bridges, tunnels, culvert structures, drainage facilities, wastewater treatment facilities, rainwater retention basins, car parks and rest areas, noise barriers or walls.

The focus of the following explanations is on the diverse fragmentation effects of roads.

Figure 9: Highway

2.6.1 Environmental impacts of roads/ highways

The impact of roads or highways on the environment has been relatively well studied. Most of the following information is taken from "IENE Biodiversity and infrastructure, Ecological effects of infrastructure" (Seiler et al. 2023).

The most important effects are:

- land use (soil sealing, direct loss of habitat)
- wildlife mortality due to traffic (roadkill)

- barrier and fragmentation effects
- edge effects on adjacent habitats
- habitat transformation linked to the infrastructure and corridor effects
- emissions (dust and pollutants, light, traffic noise)
- alterations to water bodies (surface water crossing or relocation, road drainage, lowering of groundwater level or groundwater accumulation)

Figure 10 shows the primary ecological effects produced by the physical presence of infrastructure in the landscape, their structural design, maintenance and use. Primary effects are strongly interlinked with each other and must hence be addressed and mitigated in conjunction.

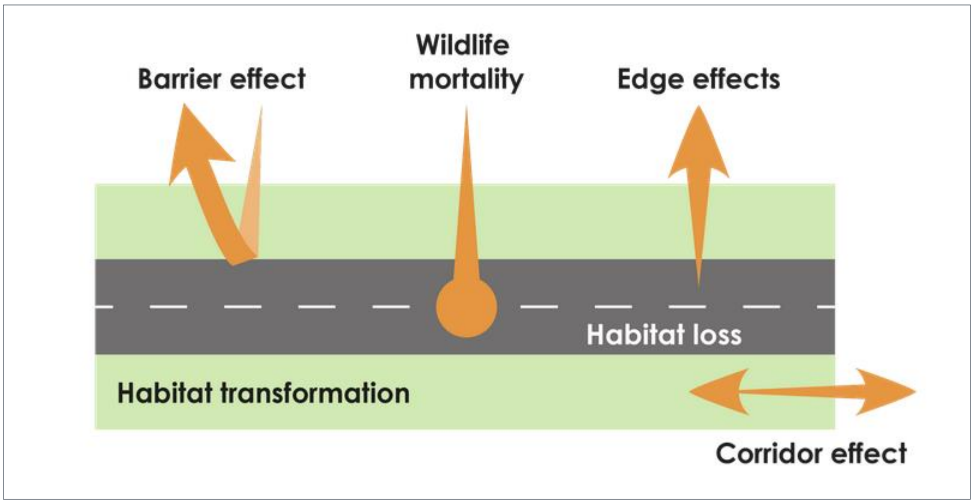

Figure 10: Simplified concept of the primary ecological effects of transport infrastructure

Source: https://www.biodiversityinfrastructure.org/handbook/1-infrastructure-effects/1-3-primary-effects/

With regard to **land use**, roads occupy a large amount of physical space and lead to a direct and immediate **loss of natural habitat**. For example, a triple-lane motorway with verges, a hard shoulder and a median strip can easily span more than 50 metres in width. Thus, each kilometre of such a highway takes up an area of about 5 ha.

The construction of new roads regularly leads to the covering or sealing of areas due to the road itself, but also due to various possible project components. This leads to an extensive loss or degradation of vegetation and animal habitats (permanent removal of vegetation) and of soils and soil functions as well as soil structure (soil sealing/degradation of soil structure).

In addition, when new highways are constructed, associated infrastructure is often required to connect local roads. These additional infrastructures contribute also to direct habitat loss and disturb adjacent areas (improved access to less disturbed sites via roads).

Roads and highways regularly cause **barrier and fragmentation effects,** which is among the most important ones.

Linear infrastructures such as roads and railways create movement **barriers** for most terrestrial wildlife. These barriers can be physical, e.g. infrastructure surfaces and fences, or behavioural, caused by noise, light and other disturbances that repel animals. The impact of these barriers varies between species, but generally they result in reduced access to resources and habitats, increased mortality and isolation of populations with consequent risks for declines and extinctions.

The barrier effect is considered as a function of three main probabilities that influence whether an animal successfully crosses an infrastructure barrier (Figure 11):

- Animals approaching the barrier may be physically stalled by fences, screens, changes in habitat or substrate.
- Some animals may be repelled by traffic noise, vehicle movement, light or human activities.
- Those animals who continue to enter the road risk getting killed by traffic, resulting in only a few individuals who successfully manage to cross the barrier.

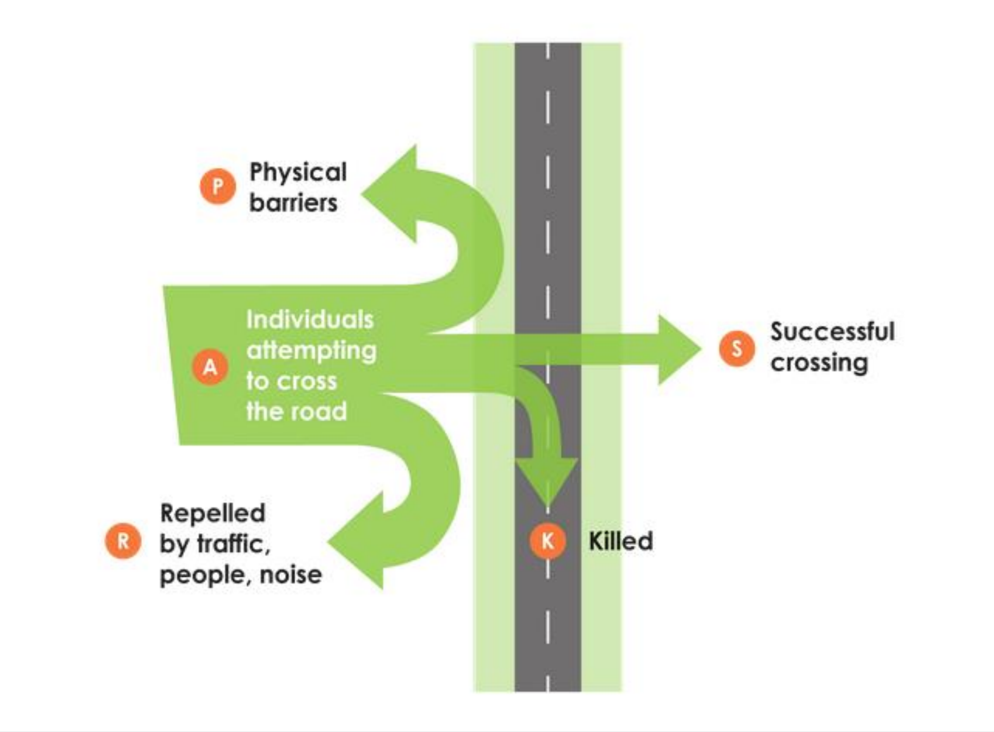

Figure 11: Main factors contributing to the barrier effect of infrastructure on wildlife

Source: https://www.biodiversityinfrastructure.org/handbook/1-infrastructure-effects/1-3-primary-effects/1-3-3-barrier-effect/

Several studies indicate that the impact of traffic and infrastructure on wildlife can be detrimental and long-lasting for both rare and abundant species. **Wildlife mortality** due to collision with vehicles (roadkill) is the result of many cascading probabilities, ranging from species abundance in adjacent habitats, landscape composition and the relative attractiveness of the infrastructure corridor, the accessibility of the driveway, traffic flow and speed and the behaviour of both drivers and animals.

Several factors contribute to creating a barrier effect on wildlife. Traffic volume, vehicle speed, number of lanes or tracks, infrastructure width and safety facilities such as median barriers, fences, noise absorbing walls, street illumination and road surface – all may influence wildlife behaviour and mobility. Table 7 distinguishes four levels of permeability according to the intensity of traffic per day.

Table 7: Relationship between road and rail traffic density and the risk for mortality and barrier effects on mammals

Road Traffic intensity	Railway traffic intensity	Effect on permeability	Mitigation approach
< 1000 vehicles per day	< 100 trains per day	High permeability for most mammalian species, but smaller species may still experience mortality and barrier effect	Mitigation may not be required for larger wildlife, but smaller species may need special solutions
1000 – 4000 vehicles per day	100 – 200 trains per day	Reduced permeability for most species, increased mortality	Focus on accident prevention, smaller species may need special solutions
4000 – 10000 vehicles per day	200 – 400 trains per day	Limited permeability for most species, high death risks	Mitigation must balance barrier and mortality effects
> 10000 vehicles per day or fenced	> 400 trains per day or fenced	No permeability for most species, very high death risk	Focus on providing safe passages, fully separate wildlife and traffic

Source: https://www.biodiversityinfrastructure.org/handbook/1-infrastructure-effects/1-3-primary-effects/1-3-3-barrier-effect

The relationship between traffic and barrier effect is non-linear and results from a combination of mortality and avoidance responses and is thus highly species specific. Small infrastructure with sparse traffic may rarely impose a barrier problem, at least to larger animals. Busy motorways and railways with multiple tracks will however be nearly impermeable for both small and large animals. The impact of intermediate infrastructure is more complex, as both, barrier and mortality effects, must be balanced. Whether mitigation efforts should focus on preventing traffic mortality needs to be balanced against the consequences to wildlife populations and traffic safety through e.g. fencing while accepting increased barrier effects, or allowing free passage while accepting a certain level of mortality, or employing alternative solutions or combinations of fences and bridges.

The barrier effect is the main contribution to habitat **fragmentation**. Transport networks not only disrupt and fragment individual habitats directly, but they also contribute to the fragmentation of the entire landscape, with fragments containing different habitats and ecosystems in the meshes of the infrastructure network. Fragmentation typically leads to a reduction in the quality, quantity and interconnection of suitable habitats. However, habitat is a species-oriented concept and hence differs between species. A forest-dwelling species will require a very different habitat than a species adapted to open grassland.

Construction, use and maintenance of transport infrastructure and associated areas have various impacts on surrounding ecosystems. They spread pollution (such as noise, light, chemical), change microclimate and groundwater flow, and help in propagating invasive alien species. These, so called **edge effects** affect not only the habitats adjacent to infrastructure (such as road verges and embankments), but also the ecosystems and living conditions of wildlife in wider areas.

The “road effect zone” captures these combined edge effects that extend beyond the infrastructure itself (Figure 12). The factors of disturbance may contain:

- Chemical pollutants: de-icing salts, exhausts from combustion engines, nanoparticles from tyre and road abrasion, pesticides used in verge management
- Physical perturbations: spread of dust, noise, light, changes in microclimate, altered ground water flows, increased erosion
- spread of invasive alien species

The distance over which disturbances affect nature depends on topography, wind direction, vegetation and the type of agent.

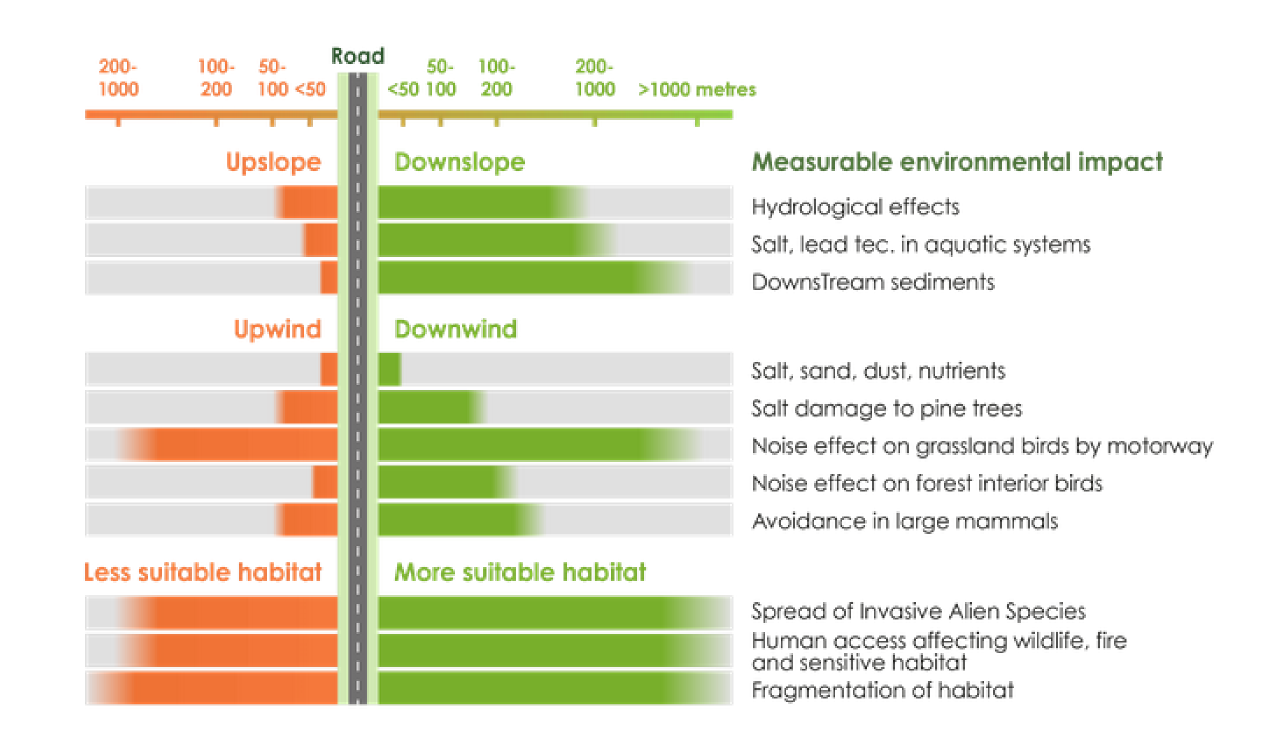

Figure 12: Edge effects spreading from infrastructure into the surrounding landscape creating the "road effect zone"

Source: https://www.biodiversityinfrastructure.org/handbook/1-infrastructure-effects/1-3-primary-effects/1-3-4-edge-effects-and-pollution/

Some effects can be expected to diminish gradually with increasing distance (e.g. deposition of dust and salt from roads), while others may exhibit thresholds in the responses of species (e.g., noise effects on breeding birds, light effects on bats). Overall, the combined impact follows a negative exponential curve with the strongest combined effects in the immediate vicinity (~ 100 m) to infrastructure and fewer impacts extending far (~ kilometres) into the surrounding landscape.

Edge effects can also cause changes in animal behaviour. When a road runs through a forest, it creates an edge habitat along the portion of the forest that fringes the road. This can have consequences for birds, as predation rates on bird nests are sometimes higher in edge habitats. This is because predators can prey on nests better in the edge, where the forest canopy offers less protection to nests.

In addition to fragmenting habitat, constructing a road alters the habitat creating a new corridor. Such **habitat transformations and corridor effects** can have positive and negative impacts on biodiversity.

Most habitats adjacent to infrastructure are managed to maintain an open, grassy vegetation that matches traffic safety constraints and minimise maintenance costs. These areas include verges, resting sites, water retention ponds and other drainage elements, as well as fauna passages. However, depending on the local conditions such as soil, water level, sun exposure, slope, and adjacent habitats, vegetation may vary greatly, creating a patchwork of areas with different potentials for biodiversity and different maintenance requirements.

With the right management, roadsides can be turned into meadows where wildflowers and wildlife flourish. Flowery verges on a nutrient-poor substrate can also provide habitat for a diversity of grassland species and hence a resource to many invertebrate species (i.e., pollinators), reptiles, birds, and small mammals that have become rare in the intensively used agricultural and peri-urban landscapes. The benefits of providing attractive or even viable resources to wildlife within transport corridors must be balanced against the risk of increased mortality due to animal-vehicle collisions. Therefore, it is essential to implement measures such as fences or screens to prevent animals from accessing the driveway while they benefit from the infrastructure habitats.

One disadvantage of newly created corridors is the possible introduction and spread of invasive alien species.

As mentioned under edge effects, roads during the operation phase are the cause of **emissions** which affect surrounding landscapes and human health: exhausts gas, debris from tyres on the road, de-icing salts, pesticides used in verge management.

Exhaust gas from combustion engines include particulate emissions from diesel engines, NOx, volatile organic compounds, carbon monoxide and various other hazardous air pollutants including benzene as well as carbon dioxide. Carbon dioxide is non-toxic to humans but is a major greenhouse gas and motor vehicle emissions are an important contributor to the growth of CO_2 concentrations in the atmosphere and therefore to global warming.

Runoff from roads and other impervious surfaces is a major source of water pollution. Rainwater and snowmelt running off of roads tends to pick up gasoline, motor oil, heavy metals, trash and other pollutants. De-icing chemicals and sand can run off into roadsides, contaminate groundwater and pollute surface waters. Road salts (primarily chlorides of sodium, calcium or magnesium) can be toxic to sensitive plants and animals.

The maintenance of road side structures (verges) using herbicides or pesticides have also negative impacts on biodiversity.

Artificial light at night – from infrastructure lighting and from vehicles – has diverse effects on wildlife, such as in reproduction, navigation or communication. Artificial light sources may attract or repel nocturnal animals, depending on their natural response to light. This attraction or repulsion phenomenon has landscape-level effects. Artificial lighting can create areas which are impassable to certain animals, finding themselves either drawn in or driven out. Artificial light at night therefore leads to habitat fragmentation and isolated nocturnal areas which contributes to habitat degradation or to the loss of species.

Motor vehicle traffic on roads generates **noise** in a wide range of frequencies which can affect both humans and animals. Traffic noise can contribute to numerous disturbances for wildlife. E.g. noise can impact birds by disrupting acoustic communication and interfering with warning signals, leading to bird population declines in the proximity of roads.

Depending on the topography and location of the road, there may also be permanent **alterations to water bodies**: e.g. surface water crossing or relocation, road drainage, lowering of groundwater level or groundwater accumulation due to cuttings and route foundations.

Due to the size of highways in particular, there is also a negative **visual impact** on the landscape.

2.6.2 Suitable locations

As with other infrastructure, roads should be built only in areas that are already degraded and are of no particular value from a nature conservation perspective, e.g. intensively used agricultural land.

2.6.3 Unsuitable locations

Roads should keep as much of a distance as possible from protected areas (e.g. Nature 2000 areas, national parks, nature reserves, core zones of biosphere reserves, water protection areas) as well as biodiversity hot spots like old-growth forests or wet- and peatland and ecological corridors defined by national or regional network concepts.

Because of the high amount of land use (soil sealing) soil with very high significance for natural soil functions are also unsuitable locations for roads.

2.6.4 Possible mitigation and compensation measures

A number of mitigation strategies have been developed to decrease the harmful impacts of roads on wildlife. The impact of transport infrastructure on biodiversity is diverse and so are mitigation measures. Most of the following information is taken from “IENE Biodiversity and infrastructure, solutions to mitigate impacts and benefit nature” (Rosell et al. 2024a).

An **appropriate route alignment** is an important mitigation measure during the planning process of a road. Route alignment and the design of earthworks should respond to the broad scale of the topography as well as to smaller-scale landforms. The guiding principle is to work with the topography using engineering elements to minimise habitat fragmentation by maximising the opportunities for connectivity below and above the infrastructure. Cuttings and embankments are components that, in general, help with route alignment. Well-designed examples can also better integrate the infrastructure with natural landforms or even provide opportunities for various habitats to be created. Tunnels may be the best solution to protect high-value landscapes.

Less traffic could mean less risk of animal-vehicle collisions and less noise, light, and chemical pollution disturbances for biodiversity. Therefore, traffic management may help to reduce impacts on biodiversity. The two main measures are a **reduction of traffic volume and a regulation of traffic speed**. These measures could be permanent at priority sections crossing vulnerable habitats, natural protected areas or other sites where traffic impacts require mitigation. They may also be temporary to take account of sensitive periods, such as breeding or migration seasons for selected target species.

Fences, if appropriately designed, installed and maintained, are one of the most effective measures to prevent animals from accessing roads. Fencing must always be combined with appropriate wildlife passages reducing the barrier effect and providing a safe crossing point for target species. Thus, fences serve two purposes: preventing animals from accessing infrastructure and guiding them to safe crossing points.

In general, wildlife fences should be installed only where there is a high risk of accidents involving wildlife or hotspots of wildlife mortality. In many countries, perimeter fences are an obligatory safety measure along high-speed railways, motorways and other busy roads. On roads with relatively low-traffic intensity, fences should be avoided or installed only in sections of particular traffic safety concern or high wildlife mortality. Extensive and unnecessary fencing imposes a barrier that, over time, could be a bigger threat to wildlife populations than traffic mortality. Other solutions to reduce wildlife-vehicle collisions such as driver warning devices and wildlife deterrents may be more appropriate in low traffic roads or railways.

A threshold traffic intensity below which fencing is not recommended must be established according to local conditions and studies. In some Nordic countries fencing is only considered at a threshold of over 4,000 vehicles per day while in many central and southern European countries the recommended threshold is 10,000 vehicles per day.

Fences should always be installed on both sides of roads or rail tracks in order to prevent wildlife accessing the infrastructure, becoming trapped there or being forced to return to the carriageway. Fences should funnel animals towards suitable wildlife crossing structures. (For more detailed information about design, dimensions, fence material etc. see https://www.biodiversityinfrastructure.org/handbook/5-solutions/5-2-fencing/)

To counteract fragmentation, both habitat connectivity and habitat suitability must be restored. This may be achieved by various measures, such as reducing noise and light pollution, limiting traffic, or installing **wildlife passages**. Wildlife crossings that allow animals to safely cross roads, are intended not only to reduce roadkill, but ideally to provide connectivity of habitat areas, combating habitat fragmentation. However, their effectiveness regarding functional connectivity remains unclear. According to Barrientos et al 2019 and Soanes et al 2024 there is abundant evidence that wildlife crossing structures allow animal movement across roads and other linear infrastructure. But there is little evidence whether wildlife crossing structures prevent the decline of movement after construction, restore movement to pre-construction levels, or even whether they are an improvement over taking no action at all (Soanes et al. 2024).

Wildlife passages should never be considered as an isolated feature. They should be an integrated part of a general permeability plan to maintain connectivity within and between animal populations and/or ecosystems. A permeability plan emphasises connectivity between habitats at regional or larger scale and considers not only the transport infrastructure but also the distribution of habitats and ecological corridors as well as other potential barriers such as built-up or fenced areas.

The number and type of measures required will depend on the target species and the distribution of habitat types in each area. In some cases, a single or a few large passages could be necessary to mitigate a local problem, whereas in other situations it may be more important to provide a large number of different types of wildlife passages suitable for a variety of target species and appropriate to connect different habitat types.

In areas that are scarcely populated or rarely trespassed by wildlife, fewer crossing facilities may suffice. However, in less populated areas, connectivity may be more crucial to maintain the viability and genetic diversity of the small remaining populations. Therefore, the location and function of ecological corridors must be considered when planning wildlife passages. Where transport infrastructure intersects with ecological corridors, mitigation measures may need to provide higher permeability than compared to where the infrastructure passes through the less suitable landscape matrix. In addition, if mitigation shall allow for the movement of a greater variety of species, passages must be large and structurally diverse enough to provide suitable conditions for their movements. https://www.biodiversityinfrastructure.org/handbook/1-infrastructure-effects/1-3-primary-effects/1-3-3-barrier-effect/

Wildlife passages can be divided in two main groups depending if they are located

- above the infrastructure (overpasses): e.g. Landscape overpass, Green bridge, Wildlife overpass, fauna overpass, multiuse overpass or
- below the infrastructure (underpasses): e.g. viaduct, fauna underpass, multiuse underpass, small fauna underpass, adapted culverts, fish passages, amphibian passages

Preserving ecological connectivity - or restoring it - should be the goal, meaning a multi-species approach is to be preferred. The choice of wildlife passage type will depend on its importance for ecological connectivity and biodiversity conservation as well as on other criteria such as main target species and topographic constraints. Different types of wildlife passages can be combined along a section of infrastructure to achieve the best reduction in landscape habitat fragmentation.

Appropriate design of crossings depends on the specific target species and will likely vary across different geographical regions. The design of passages must follow a multispecies approach not just catering for the needs of only one single target species. Usage can be maximized and effectiveness increased by including the needs of a wide spectrum of species.

Table 8 shows the recommended dimensions for different types of wildlife passages. The ranges are based on guidelines which apply in different European countries derived from local monitoring. (For detailed information about location, dimensions and design see https://www.biodiversityinfrastructure.org/handbook/5-solutions/5-5-wildlife-passages.)

Table 8: Recommended minimum dimensions for different types of wildlife passages

	Type	**Uses**	**Main target fauna groups**	**Recommended minimum dimensions (W: width; L: length; H: height; m)**
Overpasses	Landscape overpass (Ecoduct, Green bridge)	Wildlife and other uses (with appropriate landscaping)	Habitat continuity is provided. All terrestrial fauna including invertebrates and flying vertebrates (bats and birds).	W: 50 – 80 W/L > 0.4 – 0.8
Overpasses	Wildlife overpass,(Fauna overpass)	Exclusively wildlife	Ungulates, Large carnivores, other terrestrial fauna including invertebrates and flying vertebrates (bats and birds).	W: 20 – 50 W/L > 0.4 – 0.8

	Type	Uses	Main target fauna groups	Recommended minimum dimensions (W: width; L: length; H: height; m)
Overpasses	Multiuse overpass	Wildlife, livestock, pedestrian, etc.	Ungulates, Large carnivores, other terrestrial fauna including invertebrates and flying vertebrates (bats and birds).	W: 10 – 20 W/L > 0.6 – 0.8 Earthen/vegetated strips both side of trails/small roads: 1 – 2 m
Underpasses	Adapted viaduct (Landscape underpass)	Multi-use: wildlife, drainage and other	Habitat continuity is provided. All terrestrial fauna including invertebrates and flying vertebrates (bats and birds). Aquatic fauna if a watercourse runs under the structure.	H: 5; 10 in wooded areas When streams/rivers are crossed: 10 m riverbank on either side
Underpasses	Wildlife underpass, (Fauna underpass)	Exclusively wildlife	Ungulates, Large carnivores, other terrestrial fauna including several species of bats and birds.	W: 15 – 30 H: 3 – 4 For particular target species Wild boar and Roe deer: W: 5 – 10; H: 2 – 4; Red Deer/Large carnivore: W:15 – 20; H: 3 – 4;
Underpasses	Multiuse underpass	Wildlife, livestock, pedestrian, drainage, etc	Ungulates, Large carnivores, other terrestrial fauna including several species of bats and birds	W: 10 – 20 H: 3 – 4 For particular target species Wild boar and Roe deer: W: 7 – 10; H: 2 – 3.5; Red Deer/Large carnivore: W:12 – 20; H: 3 – 4; Earthen/vegetated strips both side of trails/small roads: 1 – 2 m

	Type	Uses	Main target fauna groups	Recommended minimum dimensions (W: width; L: length; H: height; m)
Underpasses	Small fauna underpass	Exclusively wildlife	Small and medium size mammals, lagomorphs and other small fauna	W: 1 – 2 H: 1 – 2 Diameter: 0.5 – 2 Minimum dimensions of 2×2 allow access for appropriate machinery to undertake maintenance tasks. Smaller structures are acceptable under specific conditions for particular target species (e.g. badger, otter).
Underpasses	Adapted culvert	Wildlife, drainage	All terrestrial fauna (depending on dimensions and other features of the structure). Aquatic fauna if a watercourse runs under the structure	Small fauna: W: 1 – 2 H: 1 – 2 Walkways (dry ledges) width: 0.5 For large mammals: see Multiuse underpass
Underpasses	Fish passage	Wildlife, drainage	Fish and other aquatic fauna	Remark: in some countries all culverts are required to be suitable for fish but also for terrestrial fauna; passages designed just for fish is not recommended
Underpasses	Amphibian passage	Exclusively wildlife	Amphibians	1×0.75 (<20m) 1.5×1 (20-30m) 1.75×1.25 (30-40m) 2×1.5 (40-50)

Source: https://www.biodiversityinfrastructure.org/handbook/5-solutions/5-5-wildlife-passages/5-5-1-types-of-fauna-passages/

Habitats related to transport infrastructure (e.g. verges, embankments, wildlife passages and drainages) can be adapted to provide refuges or food for wildlife. Embankments, for example, could mitigate noise and provide new habitats for endangered flora species, provided they are designed to avoid wildlife mortality risk. Verges are the strip of land located in the right-of-way, adjacent to carriageways and railways tracks which have several functions related to traffic safety, landscaping, land stabilisation and other requirements. Verges could be managed to benefit pollinators, providing nesting and overwintering sites or facilitating dispersal across highly modified landscapes. Daniel-Ferreira et al (2021) could show that insect movements along road verges were more frequent than movements into the adjacent habitats, indicating that verges act as corridors. Their results suggest that road verges of high quality increase functional connectivity for day-flying flower-visiting insects by reducing collision risk.

Nevertheless, attracting fauna to areas where its presence could create conflicts or put it at high risk of mortality must be avoided.

Measures to reduce **light pollution** may include:

- reducing and appropriate positioning of planned infrastructure lighting,
- selecting materials for ground surface with low reflectance to reduce upward reflection,
- limiting illumination period as much as possible, both daily and seasonally,
- infrastructure lighting using yellow/orange lights with wavelengths ~ 585nm (e.g. High Pressure Sodium lamps or Amber LED lamps with Narrow Spectrum)
- installing screens or constructing earthen mounds on verges to reduce the impact of vehicle lights, especially where the road traffic intensity is over 10,000 vehicles per day

A whole concept to mitigate light pollution is planning infrastructure lighting using the “dark infrastructure” approach, an ecological network of core habitats interconnected by “dark corridors” which traverse a variety of landscape types and which are identified based on a level of darkness necessary to preserve nocturnal biodiversity. (for more detailed information about mitigation of light pollution see https://www.biodiversityinfrastructure.org/handbook/5-solutions/5-6-measures-to-reduce-disturbances/5-6-1-lighting)

Different solutions are applied to mitigate the impact of **noise**, including placing the infrastructure between cuttings or earthen mounds, installing noise screens or using silent pavements. Some of these measures have the additional benefit of reducing wildlife traffic mortality. However other impacts, such as barrier effects, may be increased and the choice of appropriate measures should be carefully evaluated. (for more detailed information about the mitigation of noise see https://www.biodiversityinfrastructure.org/handbook/5-solutions/5-6-measures-to-reduce-disturbances/5-6-2-noise/)

In order to reduce the use of chemicals for management of green areas (infrastructure maintenance) **mechanical methods for vegetation control** can be used where infrastructure crosses sensitive areas such as natural protected areas or ecological corridors. Some alternative management methods can provide additional benefits to local stakeholders, for example livestock **grazing**. This can also contribute to the control of invasive Alien Species.

Managing the **runoff of water** from infrastructure is another key point to avoid impacts on surrounding ecosystems. Runoff water usually accumulates on verges and ditches, infiltrates the groundwater, and transports chemical pollutants to surrounding landscapes.

To avoid the spread of chemical pollutants, water collecting in drainage channels and ditches can be conducted to runoff retention ponds where solids may sediment and treatment to reduce pollution may be provided.

Retention ponds that contain water with appropriate quality (low levels of chemicals produced in infrastructure maintenance) can provide benefits to biodiversity, for example as a breeding area for amphibians. However, it is crucial that they are appropriately maintained to ensure ecological traps are not created.

2.6.5 Relevance for Environmental Impact Assessment (EIA)

According to the EU's Environmental Impact Assessment (EIA) Directive **motorways and express roads** must be assessed for their impact on the environment (Environmental Impact Assessment - EIA). For other roads, it is up to individual EU Member States to decide if there will be an EIA on a case-by-case basis or by setting specific criteria (such as the location, size or type of project).

2.6.6 Summary and perspectives for the Alps

The main environmental structural and functional effects of roads and highways include large land take with soil sealing and direct loss of habitat as well as fragmentation of ecosystems and barriers to populations of many animal species.

A combination of different mitigation measures is required to preserve or restore ecological connectivity across roads. Mitigation must consider both the barrier and mortality effects. Fencing and wildlife passages in particular have combined effects. Fences reduce the number of collisions between wildlife and vehicles, but at the same time they increase habitat fragmentation, so they must always be combined with wildlife passages that allow target species a safe crossing.

Topographic conditions and requirements are a major factor in the evolution of the Alpine road infrastructure network. The motorway network mostly follows the major Alpine valleys, where the limited available space is highly contested between transport, settlement, agriculture and other land uses (Alpine Convention 2007).

Topographic and meteorological conditions of the Alps also lead to specific transport-related environmental burdens. Particularly the valley bottoms and basins in the Alps feature unfavourable conditions for propagation of airborne pollutants (NO_2 and PM10), leading to phases with comparatively high accumulation and concentration (Alpine Convention 2007).

Compared to lowlands, mountainous territories feature different noise emissions due to mountain-specific infrastructure (bridges, tunnels, viaducts) and louder engine noise due to lower gears and higher rotational speed. Noise pollution is also intensified along mountain slopes due to the "amphitheater effect", caused by reflections and lower noise absorption through vegetation and meteorologic conditions that promote noise expansion.

Both these mountain-specific air quality and noise expansion aspects are among the justifying arguments for the EU Directive 1999/62/EC on the charging of heavy goods vehicles for the use of certain infrastructures (so-called “Eurovignette Directive”).

The Alps are crossed by several major European Transport Networks (see PlanToConnect-Policy Analysis):

- Western Balkans Corridor (Salzburg – Ljubljana resp. Linz-Graz-Maribor-Ljubljana)
- Mediterranean Corridor (Lyon/Grenoble-Torino-Milano-Verona-Trieste-Ljubljana and Nice-Genova)
- Rhine-Danube-Corridor (Munich-Salzburg-Linz-Vienna)
- Baltic Sea – Adriatic Sea Corridor (Graz-Klagenfurt-Udine resp. Graz-Maribor-Trieste)
- Scandinavian – Mediterranean Corridor (Munich-Innsbruck-Bolzano-Verona)
- North Sea – Alpine Corridor (Mulhouse-Milano)

The proposal for a regulation on union guidelines for the development of the trans-European transport network TEN-T Revision (COM (2021) 812 final) sets a timeline for completing the EU’s TEN-T core network by 2030 as well as for completing an extended core network and delivering upgraded requirements for speed a6nd quality by 2040. These requirements include infrastructural improvements both for road and rail infrastructure that could potentially affect ecological connectivity.

A continued growth is predicted for transport volumes e.g. for the 2016-2040 horizon. Total flows between Italy and Central or Northern Europe are predicted to grow by 37%, also flows between Germany/Austria and Southern or Eastern Europe are predicted to grow by 65% (Brenner Corridor Platform 2021). While new corridors for road infrastructure are generally no longer being established, significant measures are taking place in regard to retrofitting and capacity expansions of existing infrastructure.

Table 9: Synopsis Transmission lines

General environmental impacts	• land use of the road and related infrastructure, soil sealing • habitat loss due to land use (permanent removal of vegetation through covering/sealing) • wildlife mortality caused by collision (roadkill) • barrier and fragmentation effects • edge effects on adjacent habitats (disturbance that alters the species composition of nearby vegetation and habitats, reducing habitat for local native animals, propagating invasive alien species) • habitat transformations linked to the infrastructure and corridor effects • emissions (dust and pollutants, light, traffic noise) • alterations to water bodies (surface water crossing or relocation, road drainage, lowering of groundwater level or groundwater accumulation)

	• visual impact of highways on the landscape
Impacts on connectivity	• high impact on structural and functional connectivity because of usually large land take, barrier effects, wildlife mortality due to traffic and impacts due to noise, dust and pollutants
Suitable locations	• sites that are already degraded and lack threatened species like intensively used agricultural land
Unsuitable locations	• protected areas (e.g. Nature 2000 areas, nature reserves, core zones of biosphere reserves, water protection areas) • areas of high nature conservation value like old-growth forests or wet- and peatland, areas designated as ecological corridors • soil with very high significance for natural soil functions
Mitigation	• appropriate route alignment • traffic management measures: reducing traffic volume or speed • fencing combined with wildlife passages • wildlife passages as overpasses (e.g. green bridge, fauna overpass, multiuse overpass) or as underpasses (e.g. viaduct, fauna underpass, multiuse underpass, small fauna underpass, adapted culverts, fish passage, amphibian passage) reducing the barrier effect and providing a safe crossing • embankments to mitigate noise and provide new habitats for endangered flora species • adapting infrastructure verges • mechanical methods for vegetation control or grazing as alternative methods to the use of chemical substances in the management of green areas • adapting road lighting for mitigating light pollution • noise screens, placing the road between cuttings or earthen mounds, silent pavements for mitigating noise • runoff water management: Retention ponds

2.7 Railway

In addition to the railway itself (track bed with sleepers and rails), the possible project components include e.g. drainage systems, bridges and tunnels, overhead voltage lines or fences.

Figure 13: Railway: track bed with sleepers and rails

The **tracks** of a railway line usually consist of a gravel ballast (or a ballastless slab-track) with embedded wooden, concrete, or composite sleepers, which the rails are fixed onto. The ballast stabilises the sleepers and rails when temperatures fluctuate and provides the strength needed for the heavy loads carried by trains. At the same time the ballast is permeable to water and functions as a drainage system for the track. Uncontrolled, or unmanaged vegetation growth on the track bed can jeopardise the stability of the infrastructure (UIC 2023).

Drainage systems are a vitally important but complex railway asset, involving both "open" and "closed" elements that all serve the same purpose: moving water away from railway infrastructure in order to prevent instability, subsidence, flooding, dampness and other problems associated with uncontrolled water accumulation. Effective drainage systems will become even more crucial as climate change results in more extreme and unpredictable weather conditions. Drainage systems may be "natural", lined with soil and vegetation, or lined with concrete or other artificial materials (UIC 2023).

Overhead line equipment includes the masts and their supporting structure for carrying high-voltage electricity to power electric trains via a roof-mounted pantograph. The high-voltage lines transport electricity from power plants to railway substations, which are then linked with the catenary (UIC 2023).

2.7.1 Environmental impacts of railways

Many of the environmental impacts of railways on the environment are comparable to those of roads - even if the effects of railways are less well studied than those of roads (see chapter 2.6.1). Most of the following information is taken from "IENE Biodiversity and infrastructure, Ecological effects of infrastructure" (Seiler et al. 2023), the "UIC Guidelines on Managing Railway Assets for Biodiversity" (UIC 2023) and Barrientos et al. 2019.

The most important effects are:

- land use by technical structures, earthworks and operating facilities (soil sealing, direct loss of habitat)
- barrier and fragmentation effects
- edge effects on adjacent habitats
- habitat transformation linked to the infrastructure and corridor effects
- alteration of water bodies (surface water crossing or relocation, drainage, lowering or raising groundwater levels)
- wildlife mortality due to traffic
- emissions (noise, light, dust, pollutants and herbicides)
- vibrations
- visual impact of technical structures and facilities as well as prominent earthworks

Although roads and railways have similarities, they also differ in many respects, which can strongly influence their impacts. According to Barrientos et al 2019 there are five main differences:

- railway corridors are narrower than those of roads
- traffic flow is much lower on railways
- railway traffic flow is characterized by long traffic-free intervals
- railways have lower wildlife mortality when both networks are compared
- railways produce less pollutants than roads, as many trains have electric engines.

Some impacts are railway-specific. For instance, noise and vibrations produced by trains are considerably higher, but of shorter duration, than those produced by cars (Barrientos et al. 2019).

There are four main types of impacts of railways on wildlife, namely habitat loss and fragmentation, barrier effects, mortality and disturbance. As these impacts are often interrelated, their distinction is not always clear (e.g. railway-kills during dispersal can be considered as mortality, as barrier effect and as habitat fragmentation; the noise or vibration caused by passing trains can increase both the habitat loss and the barrier effect, finally leading to fragmented populations) (Barrientos et al. 2019).

The construction of a railway is directly involved in the destruction of preexisting habitats due to its **land use**. Railway-related **habitat loss** is the reduction of suitable habitat after the construction of a railway corridor, since the transformed corridor is unsuitable for several species. Habitat loss is a direct, immediate and irreversible impact which makes the choice of the alignment a critical issue (Ministry for Ecological Transition and Demographic Challenge 2021).

Habitat **fragmentation** is usually - but not necessarily - associated with habitat loss, as large fragments are progressively divided into smaller, often isolated, patches unable to maintain in many cases viable populations in the long run (Barrientos et al. 2019).

Railways can represent physical **barriers** when animals are unable to cross the transportation corridor, or behavioural barriers when animals avoid to do so. Railways represent physical barriers especially for small sized species with reduced mobility (Barrientos et al. 2019).

General information about barrier and fragmentation effects of linear infrastructures such as roads and railways are described in chapter 2.6.1. Table 7 shows the relationship between road and rail traffic density and the risk for mortality and barrier effects on mammals.

Animal **mortality** on railways often occurs due to collisions of animals with the train. The irregular traffic flow is probably one of the most important drivers influencing the mortality risk (Barrientos et al. 2019). The overhead power lines have also the potential to injure or kill wildlife, with the species at highest risk being birds and some arboreal mammals like squirrels. Within the rail corridor, these animals may become injured if they bridge the insulation and get shocked (electrocution) and may subsequently be killed by passing trains or predators on the ground. The wires of the more extensive and higher-voltage power lines supplying electricity to the rail network may pose a threat especially to migrating birds, causing collision and electrocution (UIC 2023).

Trains and railways can induce several negative effects on animal and plant populations living close to railways, including pollution (noise, light, chemical), which may contribute to habitat losses through **disturbance** effects and may exacerbate barrier effects. Disturbance impacts can be divided into those related to construction, and those others related to the operation of the railway line. During the operation phase, noise is arguably one of the most important long-term disturbances produced by trains (Barrientos et al. 2019). In the case of railways, the source of the noise is heavily dependent on the train speed. At low speeds, the noise is mainly produced by the train's power equipment while at medium or high speeds the rolling noise, produced by the contact between the wheels and the rails and the vibration this produces, becomes the most significant source. Aerodynamic noise is only a factor at very high speeds (Rosell et al. 2024a).

Little is known about the consequences of vibration and noise on biodiversity living adjacent to the railway bed (Barrientos et al. 2019).

Railway-specific structures like the tracks of a railway line, drainages, bridges and tunnels as well as fences have special impacts on the environment. They mainly relate to habitat transformation and corridor effects:

The design and structural characteristics of the **track area** result in a dry and hot habitat in summer that can be inhospitable for many plants and animals. However, the track bed mimics some extreme natural habitats, such as scree slopes and shingle beaches, and may support plants (along with the relevant insects) that have adapted to these conditions. That means that ballasted track beds can support unique communities of annual plants that depend on hot, dry and low-nutrient conditions that are otherwise rare in the surrounding countryside. On the other hand, these environmental conditions and the railway maintenance can also promote invasive non-native flora (UIC 2023).

Herbizide use for vegetation control on railway lines and along railway embankments can also represent a negative environmental impact on plants and wildlife. However, some railway companies (e.g. Deutsche Bahn[4]) have decided to phase out broad-spectrum herbizide such as glyphosate.

The management of vegetation on or near the track bed can have a major impact not only on plants, but on the species associated with them, including pollinating and herbivorous insects and the species feeding on them, such as reptiles and birds. Reptiles may use these areas as temporary sunny spots for basking on. At the same time the space between the rails and ballast surface may become a barrier for smaller animals like amphibians. On a larger scale, depending on the number of rail lines and traffic density, the network might also act as a physical and sensory barrier to larger wildlife like roe deer. This can especially affect fauna that is sensitive to noise and vibration (UIC 2023).

Although their primary function is to ensure safety and the effective operation of the rail system, the open parts of **drainage** elements, in particular, can be vital habitats for wildlife, as dragonflies and mayflies, freshwater fish, amphibians like frogs and salamanders. On the other hand, open drainage systems can also function as a barrier, particularly for smaller animals such as reptiles and small rodents that cannot cross them (UIC 2023).

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[4] https://www.deutschebahn.com/de/presse/pressestart_zentrales_uebersicht/DB-besiegelt-Glyphosat-Ausstieg-ab-2023--10414622

Bridges and tunnels can offer opportunities to enrich and protect the adjacent habitats, for example by routing a line over or under an ecologically sensitive area such as a wetland or old growth forest. Bridges, especially pillars, can be used by nesting birds and in this way function similarly to rock ledges on cliffs. However, tunnels and bridges can also have a negative impact on biodiversity. Large mammals such as deer and bears can become trapped in tunnels or on certain bridges, with no way to avoid oncoming trains. Open bridge constructions may reduce this risk, while closed constructions may increase its use as a wildlife crossing (UIC 2023).

Fences are designed to prevent people and animals from accidentally or deliberately straying into prohibited areas, with noise barriers having the additional function of reducing rail traffic disturbance for people and wildlife. On the other hand, fences can form a barrier that prevent large animals from crossing the railway line. Its impact on biodiversity is currently poorly understood (UIC 2023).

According to the environmental guidelines of the Federal Railway Authority (EBA 2016), an impact area of up to 1 km for all the above mentioned impacts on both sides of the railway track can be assumed.

2.7.2 Suitable locations

As with other infrastructure, railways should be built only in areas that are already degraded and are of no particular value from a nature conservation perspective, e.g. intensively used agricultural land.

2.7.3 Unsuitable locations

Railways should be far away from protected areas (e.g. Nature 2000 areas, nature reserves, water protection areas) as well as biodiversity hot spots like old-growth forests or wet- and peatland and ecological corridors defined by national or regional network concepts.

2.7.4 Possible mitigation and compensation measures

The possible mitigation measures for railways are similar to those for roads (see chapter 2.6.4):

- appropriate route alignment during the planning process of a railway
- Measures that aim to reduce the impact of traffic on animal populations by reducing traffic-related mortality and disturbances to adjacent habitats: fencing, adapting infrastructure verges, noise screens, earthen mounds
- Measures that aim to reduce the barrier effect of infrastructure and consequential habitat fragmentation by providing safe crossing provisions for animals and links which connect habitats: overpasses (Landscape overpasses (green bridges), wildlife overpass, fauna overpass, multiuse overpass) or underpasses (viaduct, fauna underpass, multiuse

underpass, small fauna underpass, adapted culverts, fish passages, amphibian passages)

Building fences may be a measure to avoid animal collisions, but its effectiveness can lead to increased barrier effects. Thus, this measure should be complemented with the construction of wildlife passes to maintain the infrastructure permeability. Fencing should funnel animal towards wildlife passes (Barrientos et al. 2019).

Animals use wildlife passes and other structures (e.g. drainage culverts) to cross railways. The more similar to the natural habitat a crossing structure is, the more effective it will be, as is the case of large, wide overpasses (Barrientos et al. 2019). Table 8 shows the recommended dimensions for different types of wildlife passages.

The risk of birds colliding with the wires from existing high voltage lines can be avoided by installing bird diverters (disks or small flags) to make the lines more visible. Electrocution can be avoided by extending insulators (UIC 2023).

Different solutions are applied to mitigate the impact of noise, including placing the infrastructure between cuttings or earthen mounds, installing screens, using rail noise absorbers. Some of these measures have the additional benefit of reducing wildlife traffic mortality (Figure 14). When constructed in protected natural areas, earthen mounds can also prevent traffic collision with the birds in flight. To be effective, mounds should match the height of the tallest vehicles using the infrastructure. On railways, the minimum height of mounds should be at least 4 m to direct birds above the catenaries. If the verges are not wide enough, another solution is to combine earthen mounds with acoustic screens. Vegetation in these embankments must be carefully chosen and managed to avoid creating attractive habitats for nesting, feeding and perching, which could increase the risk of mortality for wildlife (Rosell et al. 2024a).

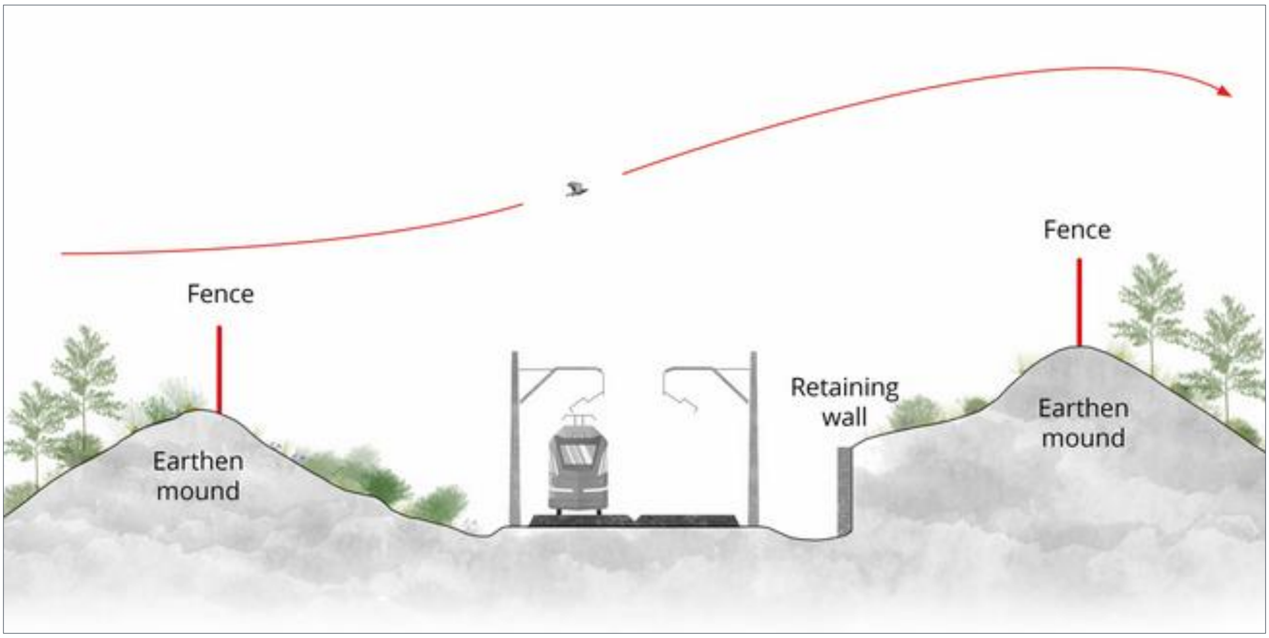

Figure 14: Cross-section of a railway located between linear earthen mounds to reduce noise

Additional screen fencing is located in the top of the mounds to force birds and other flying animals higher over the area of risk, reducing collisions with traffic or catenaries

Source: https://www.biodiversityinfrastructure.org/handbook/5-solutions/5-6-measures-to-reduce-disturbances/5-6-2-noise/

The following mitigation measures are examples to particularly reduce noise and vibrations (Rosell et al. 2024a):

- Reducing roughness. Using smooth tracks can achieve a reduction of up to 10 dB, although to be completely effective, smooth wheels are needed.
- Installation of dampers or dynamic absorbers. These are devices that absorb vibration and convert it into heat energy.
- Rail shielding. This mitigation measure aims to avoid the spread of noise. It consists of steel panels partially enclosing the rail tracks and usually includes some damping materials on the inside.

Habitat management is usually aimed to reduce the attractiveness of the railway corridor for wildlife. The railway right-of-way can act as habitat corridor, or as habitat surrogate for several species, e.g. for pollinators (bees, butterflies) (Barrientos et al. 2019).

Results indicate that transportation corridors have significant potential for habitat connectivity, especially for generalist and species specialised on open terrestrial habitats, which favour early to mid-successional habitats. Verges are particularly important in human altered environments such as urban and agricultural areas, because they provide refuges and habitat fragments which can assist in the functional connectivity of plants and animals across an otherwise hostile environment. Habitat improvements in these areas would significantly improve local biodiversity. Animal and plant physiology determines dispersal ability, which precludes a “one size fits all” approach to optimising the verge environment for dispersal. Vegetation management should therefore consider representative communities rather than individual species (Cork et al. 2024).

2.7.5 Relevance for Environmental Impact Assessment (EIA)

According to the EU’s Environmental Impact Assessment (EIA) Directive **long-distance railways** must be assessed for their impact on the environment (Biasotto & Kindel 2018). For other railways, it is up to individual EU Member States to decide if there will be an EIA on a case-by-case basis or by setting specific criteria (such as the location, size or type of project).

2.7.6 Summary and perspectives for the Alps

The main environmental structural and functional effects of railways include land take due to technical structures, earthworks and operating facilities and direct loss of habitat as well as fragmentation, barrier effects, mortality and disturbance.

Mitigation must consider both the barrier and mortality effects. Fencing and wildlife passages in particular have combined effects. Fences reduce the number of collisions between wildlife and trains, but at the same time they increase habitat fragmentation, so they must always be combined with wildlife passages that allow target species a safe crossing.

Like the Alpine road infrastructure, the railway infrastructure also has to cope with topographically challenging conditions. In large parts the railway runs parallel to the major Alpine road infrastructure. On the one hand recent developments include retrofitting and capacity expansion measures particularly along the European Transport Corridors. On the other hand the secondary network has in certain parts seen maintenance deficits and even closures in the recent past (Alpine Convention 2007).

The mountain-specific effects on traffic-related emissions (air quality and noise) have been described in chapter 2.6.6 and are in generally also applicable for railway transport, although to a lesser extent as transport volumes and propulsion systems differ. Particularly rail-related effects on air quality are mostly confined to non-electrified railway lines.

Considering the robust growth predictions for goods transport in the EU as a whole and particularly across the Alps, several major corridor improvement and expansion measures have been initiated in the Alps, most notably major base tunnels in Switzerland (New Rail Links Through the Alps NEAT), along the Brenner axis (Brenner Base Tunnel) and Lyon-Torino. The effects of these measures on Alpine transport in regard to modal shift as well as transport volumes will potentially also affect ecological connectivity. It remains to be seen to what extent particularly the base tunnels reduce the fragmentation (less frequent trains, infrastructural downscaling) along the Alpine main ridge.

Table 10: Synopsis Railway

General environmental impacts	• land use by technical structures, earthworks and operating facilities, soil sealing • habitat loss due to land use (permanent removal of vegetation through covering/sealing) • wildlife mortality caused by collision with trains (railway-kill) or wires or by electrocution • barrier and fragmentation effects • edge effects on adjacent habitats (disturbance that alters the species composition of nearby vegetation and habitats, reducing habitat for local native animals, propagating invasive alien species) • habitat transformations linked to the infrastructure and corridor effects • emissions (noise, light, dust and pollutants) and herbicide use • vibrations • alteration of water bodies (surface water crossing or relocation, drainage, lowering of groundwater level or groundwater accumulation) • visual impact of technical structures and facilities as well as prominent earthworks on the landscape
Impacts on connectivity	• high impact on structural and functional connectivity because of land take (habitat loss), barrier effects, wildlife mortality due to traffic and impacts due to noise, dust, pollutants and vibrations
Suitable locations	• sites that are already degraded and lack threatened species like intensively used agricultural land
Unsuitable locations	• protected areas (e.g. Nature 2000 areas, nature reserves, water protection areas) • areas of high nature conservation value like old-growth forests or wet- and peatland, areas designated as ecological corridors
Mitigation	• appropriate route alignment • fencing combined with wildlife passages • wildlife passages as overpasses (e.g. green bridge, fauna overpass, multiuse overpass) or as underpasses (e.g. viaduct, fauna underpass, multiuse underpass, small fauna underpass, adapted culverts, fish passage, amphibian passage) reducing the barrier effect and providing a safe crossing • embankments/ earthworks to mitigate noise and provide new habitats for endangered species • adapting infrastructure verges

	• mechanical methods for vegetation control or grazing as alternative methods to the use of chemical substances in the management of green areas • noise screens, placing the road between cuttings or earthen mounds, rail noise absorbers for mitigating noise • runoff water management: Retention ponds

2.8 Urban/ industrial development

Urban development comprises all municipal activities for the planned organisation and control of spatial and structural development within its sovereign territory. It is not confined to cities and its key instrument is municipal urban land-use planning (ARL 2018). In the context of this report urban/ industrial development means the conversion of natural and semi-natural areas for the development and the use of residential, commercial, industrial and recreational areas within previously zoned settlement areas. It includes high-density and low-density residential areas, as well as factories, industrial parks, warehouse zones and shopping centers. Recreational and leisure activities outside settlements (as included in the definition of the Natura 2000 report “State of nature in the EU-Results from reporting under the nature directives 2013-2018”, European Environment Agency, EEA Report No 10/2020, Naumann et al. 2020) are not included (see D 1.2.1).

Figure 15: Settlement

2.8.1 Environmental impacts of urban/ industrial development

When assessing the impacts of urban commercial and industrial development, it is crucial to differentiate between direct and indirect effects (UBA 2003).

Direct environmental effects

The most relevant direct impact of urban/ industrial development is the **land take**, the conversion of natural and semi-natural habitats to built-up areas (housing, settlement, recreational areas as well as commercial or industrial areas).

Land take presents both quantitative and qualitative dimensions. Quantitatively, it results in the loss of the finite resource of land. Qualitatively, it affects soil functions based on the type and density of urban development. This includes the biotope function, regulatory functions such as filtering, buffering, and water retention for flood prevention, as well as the productive function related to agriculture and forestry. Additionally, the archive function of soil, which preserves historical data and ecological information, is also compromised.

The take-up of new land for residential, commercial and industrial development is still at a high level. In addition to this quantitative increase in settlement areas, their location is also a critical aspect. Newly developed areas are often linked to existing settlement and transport areas, connecting them or creating settlement strips. Built-up areas represent an impossible barrier for many non-flying species, particularly due to their vertical elements such as buildings and enclosures. This often closes important connections between habitats or entire landscape sub-areas or creates ‘bottlenecks’ (Hänel et al. 2016). For example, urban development along streams or other traditional wildlife movement corridors may divert wildlife from traditional paths (Gregory et al. 2021).

Another significant direct effect is **habitat fragmentation**. The transformation of natural areas into urban and commercial spaces leads to the fragmentation of habitats and can disrupt ecological corridors.

Fragmentation within urbanized environments often leads to a loss of native species diversity; however, variation exists in responses among-species and among populations within species. Fragmentation due to urbanization is a multifaceted global conservation threat, altering the composition of species communities directly and indirectly. Urbanization can lead to, among other changes, the fragmentation of contiguous habitat that can alter the suitability of habitat for species. Urban infrastructures disrupt historic dispersal corridors, creating ‘islands’ of potentially suitable habitat with limited movement in between. These remaining habitat patches may have increased prevalence of invasive species, changes in predation pressure and altered microclimates associated with edge effects. Disturbance-sensitive species may become locally extinct in remaining patches while resilient species may occur at higher densities if they are able to capitalize on emptied niches (Amburgey et al. 2021).

Residential, commercial and industrial activities and structures can generate pollution to surface or ground water (e.g. rain water running from urbanised areas carrying pollutants from roads and parking plots as well as fertilizers and pesticides used for urban vegetation, discharges of urban or industrial waste water (sewage) into surface and ground waters) (Naumann et al. 2020).

Different activities and structures related to residential, commercial and industrial areas can also generate noise, light (artificial night lighting), heat or air pollution which may disturb or repel some animals (Naumann et al. 2020).

Urbanization stimulates the development of a network of local roads. Rural subdivisions require more road length per dwelling unit than more compact residential areas (Gregory et al. 2021). Increased vehicle traffic increases wildlife mortality caused by collision and has a barrier and fragmentation effect.

Urban and rural development leads to increased numbers of dogs, cats, and other pets that act as subsidized predators, killing many wild animals each year. Subsidized suburban/urban native predators such as foxes and crows, may exploit garbage and other human artifacts to reach unnaturally high density with negative impacts on native prey and disease spread (Gregory et al. 2021).

The reconstruction of existing buildings or the modification within already existing settlement areas also can have negative effects on animals and plants. For example, some man-made habitats have become important nesting or sheltering areas for birds and bats. Demolishing structures or deliberately closing damaged roofs by repairing them during breeding or hibernation can therefore harm dependent populations (Naumann et al. 2020).

Indirect environmental effects

Indirect environmental effects go beyond the immediate impact of buildings and infrastructure. Urban and industrial development is the cause of the continued growth of transport volumes, both in passenger as well as goods transport, which in turn is having negative effects on ecological connectivity (see chapter 2.6.1).

Another indirect effect is the resource consumption related to the construction of new housing and industrial development (building materials, construction machinery). The extraction of building material (wood, sand, other building components) is associated with significant environmental impacts at the extraction sites, with half of the total amount of global extraction material used for buildings and construction (EEA 2024[5]). This is also the case for renewable materials such as wood, whose extraction can be associated with land use changes (transformation of natural ecosystems, unsustainable nutrient extraction) and over-exploitation (Mishra et al. 2022; UBA 2003) that can negatively affect ecological connectivity.

Interestingly, urbanized areas may sometimes support greater habitat and species diversity compared to intensively used agricultural regions. Factors include the "…*extremely high spatial habitat heterogeneity* […] *which can produce greater species richness than surrounding rural areas especially in groups that require relatively small areas to support viable populations (e.g. plants and insects)*", the greater primary productivity (water, fertilizers, food and other limiting factors) and the high rate of dispersal of especially nonnative species (McKinney 2008). Mckinney (2008) concludes that moderate levels of urbanisation (i.e. outside of highly densified urban cores, e.g. suburban areas) show a differentiated impact on species richness: Plant studies indicate increasing species richness with moderate urbanisation whereas for invertebrate and non-avian vertebrates the situation is ambiguous (ibid).

2.8.2 Suitable locations

Suitable locations for urban and commercial development from an ecological connectivity viewpoint are either innerurban respectively brownfield development sites that have already

[5] https://www.eea.europa.eu/en/topics/in-depth/buildings-and-construction (accessed 10/15/2024)

lost their significance as habitat for flora and fauna. Development should preferably take place on these already disturbed sites.

Only if innerurban development potentials are not available to a necessary extent, then greenfield development becomes an acceptable option from an ecological point of view. Unless ecological corridors are affected, sites immediately bordering to existing urban areas pose suitable locations. As a rule of thumb, the denser, greener, smaller and compact new urban or commercial developments are, the smaller are their impact on ecological connectivity. Linear developments without intersecting green spaces should be avoided.

As with other infrastructure, urban and industrial development should be only permitted in areas that are already degraded and are of no particular value from a nature conservation perspective, e.g. intensively used agricultural land.

An obvious contradiction are the simultaneous demands for density and urban greening. Integrated urban planning that enables a high degree of density and at the same time plans and safeguards green infrastructure can be an approach to resolve this contradiction (Hansen et al. 2018).

2.8.3 Unsuitable locations

As urban and commercial developments create permanent and far-reaching disturbances of the immediate and surrounding area (built-up area, traffic volumes, recreation), isolated urban sites detached from the urban fabric should be avoided as every new greenfield development tends to encroach on the surrounding open space.

As with other infrastructure, urban and industrial development should keep a minimum distance from protected areas (e.g. Nature 2000 areas, nature reserves, water protection areas) as well as biodiversity hot spots like old-growth forests or wet- and peatland.

Because of the high amount of land use (soil sealing), soil with very high significance for natural soil functions are also unsuitable locations for new urban and industrial areas.

The development of settlement structures should be avoided in existing corridors especially in bottleneck areas. In the PlanToConnect-project, we have identified bottlenecks in the ecological network of less than 300 m that should be kept free from further urban or commercial development (see Deliverable D1.1). In mountainous territory, linear urban developments aggravate the conditions for ecological connectivity across valley bottoms that are already impaired by transport infrastructure, traffic flows and settlements.

2.8.4 Possible mitigation and compensation measures

Whenever possible, urban/industrial development should be avoided in areas of high nature conservation value including ecological corridors.

Mitigation measures include efforts to preserve large, undissected open spaces as part of green corridors in the urban fabric. Municipalities can enact tree protection decrees to safeguard ecologically valuable inner-urban trees as stepping stones. Landscaping should only be done with natural vegetation (specification of appropriate plant species is necessary). The maintenance of urban green can promote biodiversity and structural diversity through extensification, avoiding chemicals and using native plants (Moll et al. 2023; NABU 2020). Multi-coding of open spaces in urban/industrial development in the form of an integration of biodiversity aspects in open space functions such as recreation, playing areas, climatic cooling areas, water retention and infiltration areas can improve their residual function for ecological connectivity.

Unlike road barriers (which can be modified with fencing and crossing structures), urbanization creates barriers to movement which cannot easily be removed or restored. Suitable mitigation measures are keeping the building small and limiting lane width of roadways as well as keeping vehicle speeds low (Gregory et al. 2021).

Other mitigation measures are: reducing use of fertilizers and pesticides on urban lawns, minimizing water runoff into streams, minimizing artificial night lighting, encouraging pet owners to reduce domestic animal damages to wildlife (keeping pets indoors or in enclosures) (Gregory et al. 2021).

Zoning plans can promote biodiversity and ecological connectivity by coordinating compensation measures with biotope networks at municipal and regional level (see BAFU 2023:75) as well as by setting requirements in regard to greening of private and public green, buildings as well as in regard to nesting sites.

2.8.5 Relevance for Environmental Impact Assessment (EIA)

In the EU's Environmental Impact Assessment (EIA) Directive urban/industrial development is not mentioned as a subject of an obligatory Environmental Impact Assessment (EIA). However, it is up to individual EU Member States to decide if there will be an EIA on a case-by-case basis or by setting specific criteria (such as the location, size or type of project).

2.8.6 Summary and perspectives for the Alps

Given its role as major contributors to land take, it is important to address urban and industrial development in strategies to improve ecological connectivity. Their impacts are direct on-site as well as indirect in the form of transport and resource consumption. Suitable locations respect and exclude areas relevant for ecological connectivity at various spatial scales. The established guiding principle of dense, compact and integrated settlement development also benefits ecological connectivity by reducing the extent of open space that is being consumed. At the same time, it is important to pursue density and urban greening through e.g. multicoding of urban spaces (e.g. climate cooling, water retention and infiltration, biodiversity, recreation) or height extension.

In regard to current planning practices, the consideration of ecological connectivity at various spatial planning scales needs to be formalised and mainstreamed. Necessary is an urban development approach that integrates ecological, green and blue infrastructure as an indispensable element.

A specific challenge for harmonising urban development and ecological connectivity in the Alps is the topographic specificity of the Alps that reduces urban development potentials predominantly to flat landscape units particularly along the valley bottoms and the Alpine foothills. It is important to safeguard sufficient corridors within these linear structures. On the other hand, Alpine-specific scarcity of permanent settlement areas has already led to higher population densities in these areas compared to non-Alpine areas (see population density country profiles in the Report on the State of the Alps 5 "Demographic Change in the Alps" (Alpine Convention 2015).

Table 11: Synopsis Urban/industrial development

General environmental impacts	• land use by housing, settlement, recreational, commercial or industrial areas, soil sealing • habitat loss due to land use (permanent removal of vegetation through covering/sealing) • barrier and fragmentation effects • pollution of surface or ground water • pollution: noise, artificial night lighting, heat or air pollution • killing of wild animals due to increased numbers of dogs, cats, and other pets that act as predators • construction or modification (e.g. of housing and settlements) in existing built-up areas
Impacts on connectivity	• high impact on structural and functional connectivity because of land take (habitat loss), barrier effects and impacts due to noise and other pollutants
Suitable locations	• inner urban respectively brownfield sites that have already lost their significance as habitat for flora and fauna • sites that are already degraded and are of no particular value from a nature conservation perspective
Unsuitable locations	• protected areas (e.g. Nature 2000 areas, nature reserves, water protection areas) • areas of high nature conservation value like old-growth forests or wet- and peatland • existing ecological corridors, especially in bottleneck areas
Mitigation	• appropriate location of new urban/industrial development (avoid areas of high nature conservation value including ecological corridors) • preservation of large, undissected open spaces, safeguarding inner-urban trees (particularly large/mature trees) • minimizing the road infrastructure associated with urban/industrial development, keeping vehicle speeds low • reducing use of fertilizers and pesticides in maintenance of public and private green

	• minimizing artificial lighting • good pet ownership to reduce domestic animal damages to wildlife • runoff water management: minimize water runoff into streams • Integration of connectivity elements in zoning plans / optimising connectivity planning and interfaces between regional concepts and municipal planning

3 Comparison of the different infrastructures/ land uses

The table below lists the important infrastructure and land uses and assesses their impact on connectivity across the landscape. A distinction is made between structural and functional connectivity (as defined in chapter 1).

Table 12: Analysed threats to connectivity

Sector	Type of infrastructure/ Land use	Comments on Connectivity
Renewable energy	Hydropower - hydroelectric reservoir (dam)	high impact on structural and functional connectivity because of usually large land take and barrier/ fragmentation effects
	Hydropower - Run-off-river power plants	low impact on structural connectivity because of minimal land take high impact on functional connectivity because of barrier/ fragmentation effects in the water body
	Windpower - windmills	low impact on structural connectivity because of minimal land take partly high impact on functional connectivity because of collisions (birds, bats)
	Solar Power - Photovoltaics: Ground-mounted solar panels	mostly low impact on structural and functional connectivity because of usually low soil sealing and marginal barrier effects. Effects depend on the area size and design! large area photovoltaics: high impact due to extensive habitat changes (structural connectivity) and to fragmenting effects if fenced (functional connectivity). Above a length of 500 metres, fragmenting effects on large mammals are to be expected.
	Bioenergy - Biomass	Bioenergy plants: Mostly low impact on structural and functional connectivity because of usually low land take and marginal barrier effects. Effects depending on the area size of the facility! Change of land management and land use: no general statements possible because effects depend on the area size, location and intensity of the biomass production!
Energy sector as a whole	Transmission of electricity - High voltage transmission line	low impact on structural connectivity because of minimal land take outside of forests; partly high impact on functional connectivity because of collisions (birds)

Sector	Type of infrastructure/ Land use	Comments on Connectivity
Transport	roads/ highways	high impact on structural and functional connectivity because of usually large land take, barrier effects, wildlife mortality due to traffic and impacts due to noise, dust and pollutants
Transport	railway	high impact on structural and functional connectivity because of land take (habitat loss), barrier effects, wildlife mortality due to traffic and impacts due to noise, dust, pollutants and vibrations
Urban /industrial development	Urban/ industrial development	high impact on structural and functional connectivity because of land take (habitat loss), barrier effects and impacts due to noise and other pollutants

In comparison with all the infrastructures and land uses analysed, transport infrastructures like roads and railways as well as urban/industrial settlements ranked worst in terms of connectivity. This is mainly due to the large amount of land required.

Among the renewable energies analysed, hydropower is associated with the most negative impacts on connectivity. Because of the low land take, wind power performs best here.

For all sectors analysed, impacts on the environment and in particular on connectivity can be reduced through appropriate avoidance and mitigation measures.

4 Concluding remarks

Impacts and mitigation measures for transport infrastructures, settlement structures and RE

Transport infrastructures (roads, railroads) and settlement structures have negative impacts on biodiversity and connectivity mainly because of their large land take. However, impacts on the environment and in particular on connectivity can be reduced through appropriate avoidance and mitigation measures. In the initial stage of infrastructure planning, conflicts can be avoided and mitigated by taking into account ecological connectivity concepts and hotspots in the process of weighing various interests. For existing infrastructure, studies on connectivity gaps and needs for action (e.g. (Bayerisches Landesamt für Umwelt 2008)) can also provide orientation on where connectivity retrofitting is most effective. Particularly in the case of linear infrastructure such as roads and railways, the right-of-way/ embankments and directly adjacent areas can be used in the sense of a habitat network. Results indicate that transportation corridors have a significant potential for habitat connectivity, especially for generalist and specialised open grassland species, which favour early to mid-successional habitats. Verges, for example can provide a vital resource for landscape scale habitat connectivity and biodiversity by functioning as both connecting corridors and remnant habitat. Verges are particularly important in human altered environments such as urban and agricultural areas because they provide refuges and habitat fragments which can assist in the functional connectivity of plants and animals across an otherwise hostile environment (Cork et al. 2024). Wildlife passages in combination with connecting ecosystems can reduce the infrastructure barrier effect and contribute to long-term persistence of wildlife populations and to climate change adaptation.

Although all these measures support the biodiversity and habitat connectivity, the habitat loss due to the large amount of land take/ soil sealing persists and causes substantial negative effects on the environment. This applies not only to transport infrastructures, but also to urban and industrial developments.

Renewable energies examined in this report include hydropower, solar energy (ground-mounted photovoltaic), windpower, various forms of biomass energy and high-voltage transmission lines (as a necessary connection between power plants and the power grid).

Although these renewable energy sources are highly important to mitigate climate change and thereby reduce negative impacts on biodiversity, their construction and operation nevertheless have an impact on habitats and species including ecological connectivity (Naumann et al. 2020).

Among the renewable energies and the related transmission infrastructures, wind power and high-voltage power lines have the least impact on biodiversity and connectivity. Their land take is comparatively small. There are suitable measures to mitigate bird and bat mortality. However, there is a visual impact on the landscape so that windmills and transmission lines are not well accepted by the public. There is a general resistance from nature and landscape conservation organisations (Volken et al. 2011).

As for all infrastructures, the size (dimensions) and location are determining factors for the intensity of the environmental effects.

Energy demand in the European Union (EU)

There is an increasing demand for energy, especially for renewable energies. Electricity generation from wind and solar power has increased significantly in Europe over the last two decades. Planning and approval procedures have been accelerated and shortened (Meister 2023).

Renewable energy (43% of total EU energy production) was the largest contributing source to energy production in the EU in 2022.[6] Among renewable sources, the highest share of electricity came from wind turbines (15%), followed by hydropower plants (10%), solar power (8%) and biofuels (5%). (https://ec.europa.eu/eurostat/web/interactive-publications/energy-2024#eu-energy-production)

The Renewable Energy Directive sets rules for the EU to achieve its 32% renewables target by 2030. Given the need to speed up the EU’s clean energy transition, the Renewable Energy Directive EU/2018/2001 was revised in 2023. According to the European Commission hydropower is an important source of renewable energy, its flexibility and storage potential supports the EU’s electricity system. Solar power is a safe and cost-competitive renewable energy source. The EU solar energy strategy will contribute to repowering the EU. Wind energy is a mature and competitive renewable energy source in the EU, key to achieve its renewable energy targets. Biomass and biofuels help to lower the EU's external energy dependence and contribute to reducing greenhouse emissions, under the condition that sustainability criteria such as EU 2022/2448 are being met. (https://energy.ec.europa.eu/topics/renewable-energy_en)

Renewable energy in the Alps

The Alps have great potential for the use and expansion of renewable energies due to their extensive natural resources, especially water and biomass. The sustainable use of this potential can make a significant contribution to energy supply and climate protection (Kuenzer et al. 2016).

The Alps are in Europe among the few landscapes that still have wide ranging open spaces[7]. It can therefore be assumed that particularly wind turbines and photovoltaic systems will increase in the Alpine region.

[6] Nuclear energy (28%) was the second largest source, followed by solid fuels (19%), natural gas (6%) and crude oil (3%).

[7] Open spaces comprise areas outside housing/settlement areas, commercial/industrial areas and other special designated areas that are kept free from building developments of any kind, which are not predominantly developed (punctual, linear or planar infrastructure) and are widely free of soil sealing, ideally free of traffic or largely reserved for

However, the potential for renewable energies is limited by topographical conditions. For example, around 28% of the land in the Alpine region is designated as protected areas. Around 16 % are located at an altitude of over 2,000 m. In addition to small-scale nature conservation areas, larger protected areas are of particular importance, including national parks, biosphere reserves and nature parks. There are also World Heritage Sites and NATURA 2000 areas. The use of renewable energies is not possible or only possible to a very limited extent in these areas due to their strict protection status (Kuenzer et al. 2016).

Hydropower and forest biomass are traditional energy sources in the Alpine region and represent the greatest RE contribution today. Other RE sources such as solar energy, wind energy, biogas, and agricultural biomass are increasingly used (Hastik et al. 2016).

In the Alps most **hydropower** potential is already realized. Remaining hydropower potentials need to be reconciled carefully, as most of the bigger rivers are already intensively used and small hydropower projects tend to impact river ecosystems to a disproportionate extent in relation to the amount of energy generated (Hastik et al. 2016). Furthermore, the potential for expansion is limited, as the structural installations can have a considerable impact on nature and biodiversity and thus cause high costs for ecological compensation measures (Kuenzer et al. 2016), particularly in regard to the Water Framework Directive and the Nature Restoration Law and its objective of restoring 25,000 km of free-flowing rivers by 2030.

The majority of **wind energy** in the Alps is generated on ridges or crests located outside or on the edge of mountain regions. The potential for wind power therefore lies largely in the non-Alpine areas. Compared to windy coasts such as those in northern Europe, the wind yield and therefore energy production in the Alps is only average. Many potential sites for new wind turbines are located in protected areas. This means that the expansion of wind power in the Alps can only be expected to a limited extent (Kuenzer et al. 2016).

The climatic, geographical and morphological conditions in the Alpine region must be taken into account for the production of electricity from **solar energy** in the form of ground-mounted systems. This results in very different potential in the respective countries: Italy and France have a higher potential due to the southern exposure of their valleys and the more intensive solar radiation (Kuenzer et al. 2016).

Forest cultivation has a long tradition in the Alpine region. The use of forest **biomass** therefore represents a significant proportion of renewable energy production (Kuenzer et al. 2016). Available forest biomass potentials already seem to be utilized to a large extent (Hastik et al. 2016) and the need to secure topsoil and its qualities and nutrients in the context of forestry has to be increasingly considered (EU 2022/2448).

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non-motorised traffic and thus "noise-free". Technical infrastructures not belonging to the landscape structure are either non-existent or hardly existent (Job et al. 2017).

Comparing energy potentials and current energy production reveals that solar energy has the highest potential for expansion, followed by wind energy and hydropower. In some regions, agricultural biomass could be used as a supplementary energy source (Hastik et al. 2016).

The expansion of REs generates new conflicts between energy production and nature conservation goals. This is particularly true for mountainous areas such as the Alps because of their fragile ecosystems, high biodiversity, highly appreciated aesthetic and recreational values, and increasing land use pressure (Hastik et al. 2016).

Another problem in the Alps is the difficult accessibility. For all kinds of energy production appropriate access infrastructures like roads, power lines, sites for construction and future maintenance etc. are necessary. However, due to the topography the existing access infrastructures in mountainous areas are usually not sufficiently developed. This means additional environmental impacts which has to be taken into account.

Need for spatial planning

As already mentioned the location of a planned infrastructure plays a major role. This is particularly important for mountainous areas as the Alps.

In Environmental impacts assessments (EIA) usually only small-scale alternatives are considered. This seems to be insufficient. The selection of environmentally compatible areas at a higher spatial planning level is necessary. It would be important to have a large-scale master plan for the entire Alps, where and what kind of infrastructures are still possible. Spatial planning competences and mandates, however, are strictly confined to national or federal state administrative units. Therefore, a framework for supra-national spatial planning in the Alpine region would facilitate a comprehensive planning approach.

Apart from this broader perspective, appropriate spatial planning is the key to directing locations for RE or other infrastructures to suitable areas also from an ecological connectivity point of view.

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Annexes

Annex 1 Glossary

Bioenergy	Bioenergy is energy derived from any form of biomass or its metabolic by-products. Bioenergy comprises the heat, electricity, cooling, and transport fuels produced from biomass
Biomass	Biomass is renewable organic material that comes from plants and animals. Biomass sources for energy include: • Wood and wood harvesting and processing residues and wastes: firewood, wood pellets, and wood chips, lumber and furniture mill sawdust and waste, and black liquor from pulp and paper mills • Agricultural crops, residues and waste materials: corn, soybeans, sugar cane, switchgrass, woody plants, and algae, and crop and food processing residues • Biogenic materials in municipal solid waste: paper, cotton, and wool products, and food, yard, and wood wastes • Animal manure and human sewage for producing biogas/renewable natural gas
Hydropower (dams, weirs, run-off-the-river)	power derived from the energy of falling water or fast running water to generate electricity Hydropower generation including development and use of associated infrastructure (e.g. building dams or weirs, changes of hydrological functioning rivers or chemical and thermal properties of water due to operation of dams and weirs).
Hydroelectric dam	a barrier that stops or restricts the flow of water; used to create energy in the water flow that can be captured by a turbine to generate electricity
Hydroelectric reservoir	the body of water formed upstream by the creation of a hydroelectric dam
Hydropeaking	discontinuous release of water to accommodate peaks of energy demand
Impoundment reservoir	a body of water confined within an enclosure, for example behind a dam

Pumped storage hydropower	Pumped storage hydropower (PSH) is a type of hydroelectric energy storage. It is a configuration of two water reservoirs at different elevations that can generate power as water moves down from one to the other (discharge), passing through a turbine. The system also requires power as it pumps water back into the upper reservoir (recharge). PSH acts similarly to a giant battery, because it can store power and then release it when needed.
Solar Power	Renewable energy (solar power) generation including development and use of associated infrastructure (e.g. building solar farms).
Solar photovoltaic (PV)	the direct type of solar energy in which photons from solar radiation are converted to electricity
Solar PV panel	an arrangement of PV materials that absorbs and converts sunlight into electricity
Transmission lines	power lines used to move electricity from a generating site (e.g., a power plant) to an electrical substation, which often transforms the voltage from high to low before reaching consumers
Wind farm	a group of wind turbines used to produce electricity
Wind power	the use of air flow through wind turbines to mechanically produce electricity
Wind turbine	a device with two or three propeller-like blades which in the presence of wind turn around a rotor, spinning a generator to produce electricity

PlanToConnect

Mainstreaming ecological connectivity in spatial planning systems of the Alpine Space

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