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PlanToConnect

Mapping report of priority connectivity areas for spatial planning and GBI typology catalogue

An in-depth analysis of a potential ecological network and of human barriers in the EUSALP area

Deliverable D1.1.1 to create a knowledge base for green and blue infrastructure connectivity planning.

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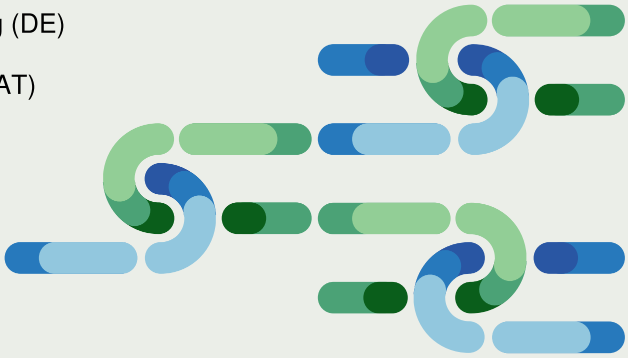

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1 Introduction

Ecological connectivity (EC) plays a fundamental role for the protection of biodiversity. Reviewing the definitions on EC of the last decades (see section 8), for the PlanToConnect project it is most appropriate to see ecological connectivity as “the unimpeded movement of species and the flow of natural processes that sustain life on Earth” (UNEP - CMS, 2020).

Spatial planning is commonly recommended to improve ecological connectivity, by counteracting landscape fragmentation, and by protecting existing green and blue infrastructure networks (Perrin et al., 2019; Plassmann and Coronado-Cortes, 2023). Many recommendations from European project on EC like the Interreg Alpine Space ECONNECT project (2008 - 2011) (Walzer et al., 2011) and Interreg Alpine Space AlpBioNET2030 project (2016-2019) (Plassmann et al., 2019) refer to a better implementation in spatial and landscape planning tools, “*because the achievement of ecological connectivity requires interdisciplinary planning processes and measures”* (Walzer et al., 2011).

Spatial planning refers to the methods used by the public sector to influence the distribution of people and activities in spaces at various scales as well as the location of the various infrastructures, recreation and nature areas. Spatial planning activities are carried out at different administrative or governmental levels (local, regional, national), while activities of cooperation in this field are also implemented in cross-border, transnational and European contexts (CEMAT, 2007).

In a transnational European dimension spatial planning refers to regional planning, which contributes to a better spatial organization in Europe and to the finding of solutions for problems which go beyond the national framework. Thus, spatial planning aims to create a feeling of common identity, having regard to international relations. Perrin et al. (2022) analysed the EU framework for EC and its practical spatial implementation and came to the conclusion that although there is no strict binding framework at the European Union level to address ecological connectivity, the ambition in the field is growing, considering the numerous initiatives show that it exists, like the adoption of directives on biodiversity with certain considerations for this issue, the promotion of new concepts such as the one regarding green infrastructure, and the inclusion of specific objectives within the EU Biodiversity Strategy.

However, according to Perrin et al. (2019), spatial planning administrations have not yet fully included ecological network concepts in Alpine spatial planning systems. Due to the lack of a common framework on EU level, there is a high diversity of different approaches at regional level (Perrin et al., 2022). Harmonization problems arise at national and regional borders, which was confirmed by analyses in scope of the PlanToConnect project (see Deliverable 2.1.1 – Planning instruments and processes for GBI network planning and implementation in the Alps). Additionally, Natura 2000 sites are representing patches of protected areas rather than a coherent network. A lack of coordination of Natura 2000 at transnational level, but also on the national level is existing. (Opermanis et al. 2012 and 2013).

To consider EC in a cross-border perspective, the ECONNECT project elaborated a functional model with target species within the Alpine Convention area to respond to the demand for cross-border actions. Structural models with combination of indicators for landscape permeability were elaborated for pilot sites (Walzer et al., 2011) and several studies analysed structural ecological connectivity of many parts of the Alps. For example, Ferretti & Pomarico (2013) conducted an ecological land suitability analysis through spatial indicators for Piedmont and recently, Staccione et al. (2022) developed a model for green infrastructure network based on riparian zones in northern Italy.[1]

The first structural connectivity model for the whole EUSALP area was developed in the ALPBIONET2030 project defining three categories of intervention types. However, it resulted in very vast intervention areas with coarse delineation, and a reduced barrier analysis, without specifying targeted sectors. Therefore, this mapping activity in the Interreg Alpine Space PlanToConenct project investigates the structural connectivity in the EUSALP area more in detail to propose intervention priorities with relevance for spatial and landscape planning.

The main question for this project activity is:

- How can more detailed priority areas for ecological connectivity be identified from alpine–wide to regional and local scales, that are useful for spatial planning purposes?

Consequently, three sub-questions arise to respond to this question:

- Which potential ecological linkages contribute most to the coherence of the overall ecological network?
- Which of these linkages have bottlenecks and are at risk by urbanisation that could be prevented by spatial planning processes?
- Where and what are the most important anthropogenic barriers?

Green and Blue Infrastructure (GBI) networks

In parallel to the strictly biodiversity-focused approach, a strategy to develop green and blue infrastructure (GBI) was elaborated by the EU in the last decade, which was broadly defined:

"*Green Infrastructure (GI) are defined as 'strategically planned networks of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas. On land, GI is present in rural and urban settings.*" (European Commission 2013 & 2021). This network of green (land) and blue (water) spaces can improve environmental

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[1] For the difference between functional and structural connectivity, please see section 8

conditions […] and enhances biodiversity. The Natura 2000 network constitutes the backbone of the EU green infrastructure. (EC 2021)

With its wide-ranging spectrum of landscape components and its multifunctional approach including biodiversity and ecosystem services, it became a useful approach for land-use planning applications (Pedrazzini, 2017; Pristeri et al., 2023). The guidelines for connectivity planning of the European-wide NATURACONNECT project to design a coherent and trans-European nature network describes that *"connectivity is one of the principles of GBI design, along with multi-functionality and spatial planning (Estreguil et al., 2019). The social and ecological benefits of GBI depend to a large degree on connectivity (Benedict and MacMahon, 2002; Ignatieva et al., 2011; Petrisor et al., 2021)."* (Moreira et al. 2024).

In an urban context, GI has been understood as a strategic approach to open space or landscape planning to fulfil a wide range of ecological, social, and economic objectives as well as a narrowly focused spatial solution to local storm water management (Fletcher et al. 2015, p. 533). While the general approach can be used for the PlanToConnect project, the focus of the project will be extra-urban areas.

Similar approaches such as ecological networks and green space planning had been implemented before and alongside (the development of GI concept) in many countries (Nordh and Olafsson 2020; Grădinaru and Hersperger 2018).

1.1 Definitions for the PlanToConnect project

To respond to the mentioned questions, the PlanToConnect project developed a GIS model for structural connectivity with potential ecological linkages based on the ALPBIONET2030 project results. Specifically, the following results in form of GIS data were used for the in-depth analysis:

Ecological Conservation Areas (SACA1)

SACA1 areas were the basis for ecological connectivity modelling in the PlanToConnect project. The term was developed in the ALPBIONET2030 project and is defined as "*areas, that still have considerable space for connectivity with non-fragmented surfaces and where connectivity should be conserved*". According to Plassmann et al. (2019), currently 61% of the Ecological Conservation Areas within the Alpine Convention perimeter are located in protected areas, which means there is a big potential for protection of these areas.

Ecological Intervention Areas (SACA2)

The main focus in the PlanToConnect project lies on areas for possible interventions to improve ecological connectivity. The ALPBIONET 2030 project simulated such areas with very large extension and developed the term "Ecological Intervention Areas". These are areas "*with a high potential for connectivity in which larger, more or less natural non-fragmented zones could be created, especially by connecting protected areas, Natura2000 sites or other precious biotopes. Ecological connectivity is currently working to some extent in these areas but would benefit from enhancements*" (Plassmann et al. 2019).

Connectivity Restoration Areas (SACA3)

"*They are areas where fragmentation has already progressed so far that realizing (sic!) interlinked habitats and a permeable (sic!) landscape matrix is no longer a realistic option using reasonable, viable interventions, and solutions would entail extreme financial and political effort. They represent important barriers between Ecological Conservation Areas*" (Plassmann et al. 2019). The realization of punctual interventions at very targeted locations to mitigate negative barrier impacts is recommended (ibid.).

Connectivity areas (at large scale)

The PlanToConenct project will focus also on the so-called "Connectivity areas", which were defined in ALPBIONET2030 at large-scale. These areas are "*strategic regions, where protection, planning and specific ad-hoc measures are necessary to avoid isolation of Alpine biodiversity at the Alpine periphery and to allow the conservation of large-scale wildlife corridors reaching neighbouring mountain massifs*". (Plassmann et al. 2019). These potential connections were identified through an international expert workshop and represent therefore valuable opinions.

The following definitions were elaborated for the PlanToConnect project to reach the same understanding of technical terms and to retain them over the duration of the project.

Potential ecological linkages

After reviewing the scientific definitions of ecological linkages (see section 8 - Scientific and EU policy definitions of technical terms), 'potential ecological linkages' are seen as geographically identified landscape elements, resulting from a connectivity model, which are connecting important ecological areas. These can be protected areas, Natura 2000 sites, or Ecological Conservation Areas as defined by the ALPBIONET2030 project.

Potential linkages are mostly a result of modelling approaches, calculated by the least cost paths, circuit theory (like SACA2), randomized shortest paths, or other methods. The term is commonly used in ecological network modelling, also in scientific literature (cf. Zhang & Song 2020).

Priority connectivity areas for spatial planning

"Priority connectivity areas" for spatial planning are areas important for the overall Alpine ecological network, where specific provisions aimed at preserving or re-establishing ecological connectivity should be included in national and regional spatial plans.

It is possible to define different types of priority connectivity areas from large-scale level to small-scale level:

Table 1: Types of priority connectivity areas at various scales

Macro - regional	1) Large scale "connectivity areas" (for the definition see ALPBIONET), where measures are still needed.
Transnational to regional	2) SACA1 areas not protected and outside the Natura2000 Network.
	3) Potential ecological linkages
Local	4) "Potential corridors" <5km of the Alpine Parks 2030 project*, which are currently not protected or managed. *The Alpine Parks 2030 project defined potential corridors through intersecting buffer zones of 2,5km around SACA1 areas, if they are within an SACA2 area (Ecological Intervention Area) defined by the ALPBIONET2030 project. Within SACA2 areas there is a high potential for connectivity.

Alpine priority planning "hot spots"

"Hot spots of ecological connectivity" are near natural areas on a local level, with a high landscape permeability characteristic, important for ecological connectivity. The project defines "hot spots" as concrete areas on a local level, which mostly are limited in extension.

2 Concept for identifying priority connectivity areas for spatial planning

2.1 Objectives at various levels and sectors to be analysed

Objectives of priority connectivity areas at various levels

Priority connectivity areas at macro – regional level:

1. Objective: To prevent that the Inner Alpine area (Alpine Convention perimeter) becomes a biological island and to preserve the remaining open passages.
    - Method/ criteria: Consideration and more detailed analysis of "connectivity areas" from the ALPBIONET2030 project.

Priority connectivity areas at transnational to regional level:

2. Objective: To preserve the existing highly permeable landscapes in the regions/ preserve the connectivity of the regions and fulfil the EU objective of protecting 30% of the landscape surface.
    - Method/ criteria: Identify SACA1 areas, which are not protected.

-

3. Objective: Identifying ecological linkages that are important for creating a coherent alpine network for a real transnational ecological network.
    - Method/ criteria:
        a. Elaboration of an Alpine ecological network based on network theory, identifying potential ecological linkages.
        b. Identification of its "minimum spanning tree" and "centrality" and adding "connectivity areas" identified by the ALPBIONET2030 project.

4. Objective: To conserve the existing ecological linkages by spatial planning, to lower the risk of getting linkages lost by urban and infrastructural development and to restore potential corridors by connecting GBI elements.
    - Method/ criteria: Evaluation of urbanisation threat for regional ecological linkages and identification of bottlenecks or pinch points of potential regional linkages.

Priority connectivity areas at local level:

5. Objective: To connect Ecological Conservation Areas for avoiding their fragmentation and possibly increasing the size of existing protected areas by constructing a type of “buffer zones”.
    - Method/ criteria: Use of “potential corridors” of the ALPINE PARKS 2030 projects as a result at local level, identifying potential linkages < 2,5km between SACA1 areas.

Sectors of barriers and infrastructure development to be analysed in activity 1.1

In coherence with activity A1.3 “Assessment of major emerging threats posed to GBI ecological networks”, barriers and developments of those sectors were analysed, on which spatial planning can have a major influence. The selection of sectoral policy fields to be analysed in activity 1.3 was in general proposed for infrastructural projects, specifically it refers to the following ones:

- Settlement development, including all types of buildings, residential and industrial.
- Transport, with focus on motorway barriers.
- Energy, with focus on large solar panel fields in open landscapes.

Due to the lower barrier effect of agriculture and tourism activities on EC, and due to limited influence of spatial planning on agricultural practices, the potential linkages passing through intensive agricultural areas and ski resorts will be analysed in activity A1.2 regarding compatible and conflicting anthropogenic uses.

- Intensive agriculture
- Tourism & recreation

Thematic scope: The project aims to enhance the following actions:

- to define ecological corridors (i.e., continuous corridors or steppingstones) and improve their permeability,
- to decrease the barrier effect of linear infrastructures and the risk of getting lost by urbanization,
- to create new protected areas and/or expansion of other existing protected areas.

2.2 Options for improving ecological networks

There are several options for improving an ecological network. A review of England's wildlife and ecological network (Lawton et al., 2010) revealed five key approaches to rebuild nature and to address the weaknesses of the wildlife sites identified at this time:

i. Improve the quality of current sites by better habitat management. (a)
ii. Increase the size of current wildlife sites. (b, c)
iii. Enhance connections between, or join up, sites, either through physical corridors, or through steppingstones. (d, e)
iv. Create new sites. (f)
v. Reduce the pressures on wildlife by improving the wider environment, including through buffering wildlife sites. (g, h)

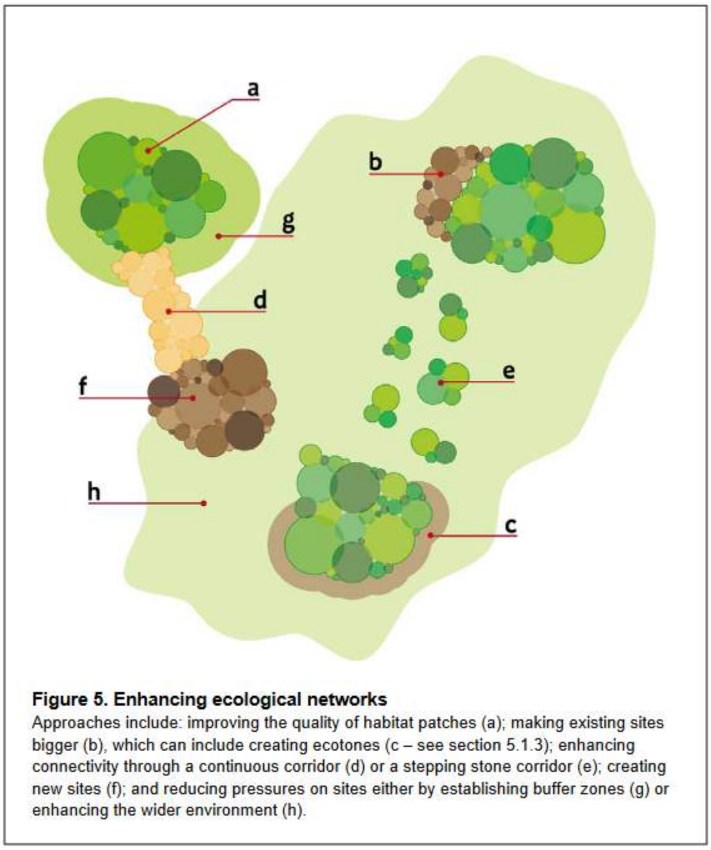


Figure 5. Enhancing ecological networks
Approaches include: improving the quality of habitat patches (a); making existing sites bigger (b), which can include creating ecotones (c – see section 5.1.3); enhancing connectivity through a continuous corridor (d) or a stepping stone corridor (e); creating new sites (f); and reducing pressures on sites either by establishing buffer zones (g) or enhancing the wider environment (h).

(Lawton et al. 2010)

Figure 1: Options for improving ecological networks

Considering the existing data and conducted analysis in the Alpine Space, the concept for improving ecological networks of (Lawton et al. 2010) and described in detail by Lausche et al. (2013) can be transposed to the reality of the Alps. The PlanToConnect project is giving an interpretation of the five options by using Alps-wide data. The localisation of such options can be considered as **priority connectivity area for spatial planning**.

Option i. Improve the quality of current protected areas or Natura2000 sites, not SACA1.

a) Improve the quality of current protected areas or Natura2000 sites, not SACA1.

SACA1 areas are indicating a low value of anthropogenic influence and a high value of naturalness. According to the ALPBIONET2030 model, 68.3% of protected areas or Natura 2000 sites are not classified as SACA1 areas within the EUSALP region. This is showing a potential for improvements of existing protected areas.

b) Improve the protection status of the Natura2000 network.

NATURA2000 have not the same protection status as protected areas but the overlap with protected areas is very high. The redundancy is about almost 60% and often the status ("favorable conservation status") of the NATURA2000 sites is quite comparable to protected areas (ALPARC 2023). The habitat directive is not prohibiting human activities within Natura 2000 sites, but anthropogenic uses must not cause damages to the habitats of the protected species. A part of the airport of Munich e.g., is located within a Natura2000 site. The Natura 2000 site Montello in Veneto, Italy (site code IT3240004) e.g., is strongly fragmented by single houses and farms.

Within the Alpine Convention perimeter 41,6 % of the Natura2000 sites have no additional formal nature protection status.

Table 2. Protected Natura2000 sites and Key Biodiversity Areas **within the Alpine Convention perimeter**

PA	Weak PA, Alpine Convention		Strong PA, Alpine Convention		Total Overlay, Alpine Convention		Total surface within the Alpine Convention perimeter by category (KBA – Natura 2000)
	Surface km²	%	Surface km²	%	Surface km²	%	Surface km²
KBA	6,338	18.1%	13,361	38.2%	19,700	56.4%	34,949
Natura 2000	7,278	18.8%	15,302	39.6%	22,581	58.4%	38,683

Source : ALPARC 2023©

Considering the whole EUSALP region it shows a better picture. Approximately 32% of all Natura 2000 sites in the EUSALP region are not protected with additional nature protection category:

- Natura 2000 areas, which are not protected correspond to approximately 39,030 km².
- The total area of Natura 2000 sites within the EUSALP macro- region is approximately 119,040 km².

Option ii. Increase the size of current protected areas according to SACA1 areas that are not yet protected.

The analysis in ALPBIONET2030 revealed areas with a high naturalness and high values for landscape permeability, although they are not protected. Such areas are indicating suitable locations for protection measures, which at the same time can contribute to the creation of a coherent ecological network.

Figure 2 is showing a SACA1 areas buffering the Natura 2000 sites “Tiroler Lech” (AT3309000) and “Vilsalpsee” (AT3302000), near Reutte, Tyrol, (AT).

Figure 2: SACA1 areas buffering Natura 2000 sites near Reutte, Tyrol (AT)

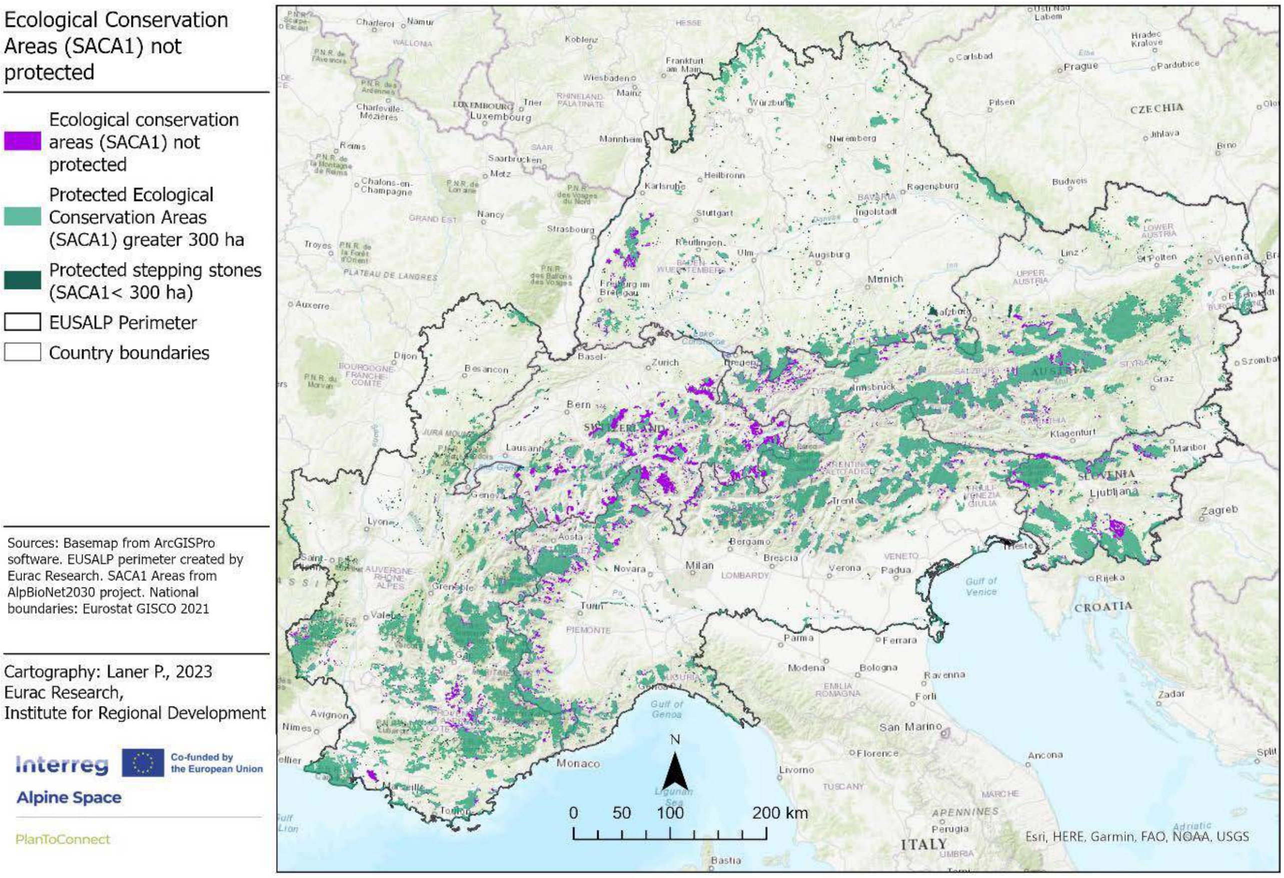
Option iii. Enhance linkages between SACA1 areas

This option should focus on potential linkages on regional level, with a length of more than 2,5 km. Potential linkages between SACA1 areas of less than 2.5 km are considered as buffering wildlife sites in option v, as in Figure1, from Lawson et al. (2010).

As it is one of the most important options that spatial planning can contribute, the PlanToConnect project elaborated a detailed analysis on potential ecological linkages on an Alpine wide level in section 3 "GIS model for the identification of priority connectivity areas".

Option iv. Create new protected sites in SACA1 areas which are not protected.

In total, 8,1% of SACA1 areas, are located outside protected areas or Natura2000 sites and most of them appear in Switzerland.



Sources: Basemap from ArcGISPro software. EUSALP perimeter created by Eurac Research. SACA1 Areas from AlpBioNet2030 project. National boundaries: Eurostat GISCO 2021

Cartography: Laner P., 2023
Eurac Research,
Institute for Regional Development

Figure 3: Ecological Conservation Areas (SACA1) not protected

Table 3: Ecological Conservation Areas (SACA1) not protected by country

Country	**Patches**	**km²**	**% of SACA1 surface area not protected**
Liechtenstein	2	0.2	0.37 %
Germany	282	266.7	5.83 %
Slovenia	261	347.3	7.54 %
France	710	411.5	3.45 %
Austria	903	505.5	4.53 %
Italy	1,064	580.1	4.90 %
Switzerland	596	1,729.2	36.04 %
Sum	3,818	3,840.5	

The coverage percentages presented in Table 3: Percentages of SACA1 areas according to their protection status, only concern the data from the WDPA – World Database on Protected areas and the Strategic Alpine Connectivity Areas (SACA 1) larger than 1km². The overlayed surfaces are presented for the EUSALP and Alpine Convention perimeters and are subdivided into two different lines:

- The overlayed surfaces between the SACA 1 and the selection of the surfaces under the IUCN categories I, II, III and IV.
- The overlayed surfaces between the SACA 1 and all the categories from the WDPA including all the IUCN categories and other national designations.
- The overlayed surfaces between the SACA 1 and all the categories from the WDPA (including all the IUCN categories, other national designations, and Natura 2000 / Emerald network)

Table 4: Percentages of SACA1 areas according to their protection status

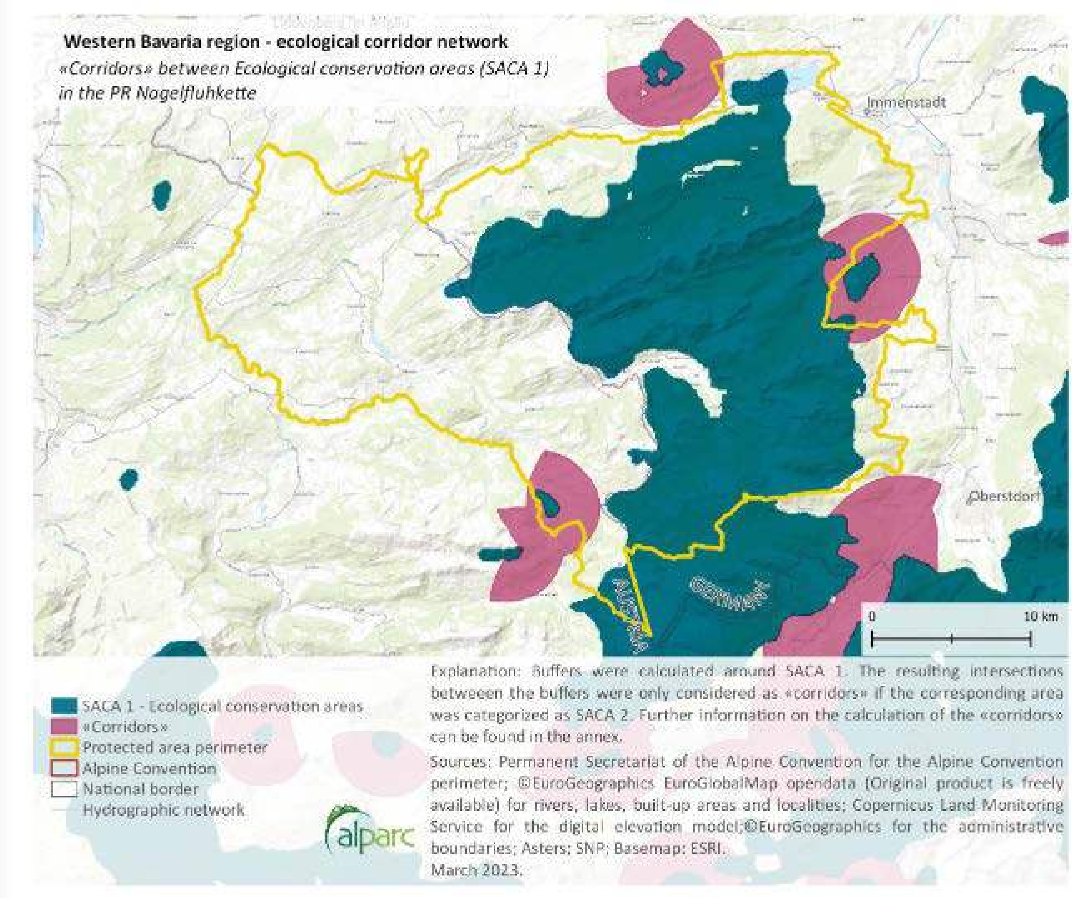
	EUSALP surface km²	**AC surface km²**	**% of total SACA1 EUSALP**	**% of total SACA1 AC**
SACA 1 covered by IUCN categories I-IV	17 708	16 278	37%	42%
SACA 1 covered by a WDPA category (IUCN and other National Designations)	32 886	27 103	69%	70%
SACA 1 covered by a WDPA category*	42 084	34 643	88%	90%
Total surfaces of protected areas from WDPA	126 675	64 764		
SACA 1 (larger than 1km²)	47 815	38 565		

*Includes IUCN and other protection categories. Natura 2000 and Emerald networks included.

Source : ALPARC 2023©

Option v. Buffering wildlife sites:

The Alpine parks 2030 project[2] elaborated an analysis of potential ecological corridors for SACA1 areas which are closer than 2.5 km to each other. The example of the pilot site Nagelfluhkette around the protected area Allgäuer Hochalpen shows a high potential for improving and defining ecological corridors by simply buffering areas with a high naturalness.



Explanation: Buffers were calculated around SACA 1. The resulting intersections betweeen the buffers were only considered as «corridors» if the corresponding area was categorized as SACA 2. Further information on the calculation of the «corridors» can be found in the annex.

Sources: Permanent Secretariat of the Alpine Convention for the Alpine Convention perimeter; ©EuroGeographics EuroGlobalMap opendata (Original product is freely available) for rivers, lakes, built-up areas and localities; Copernicus Land Monitoring Service for the digital elevation model;©EuroGeographics for the administrative boundaries; Asters; SNP; Basemap: ESRI.
March 2023.

Figure 4: Example of buffers between protected areas Nagelfluhkette and Allgäuer Hochalpen

Source : ALPARC 2023©

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[2] https://alparc.org/parks2030

3 GIS model for the identification of priority connectivity areas

3.1 Concept for the identification of “potential regional linkages with a high priority”

The identification of potential regional linkages with a high priority will follow the graph theory and will use the least-cost path (LCP) analysis.

Graph theory is the study of graphs that formally represent a network of interconnected objects. Graph theory provides the basis for nearly all connectivity methods, including least-cost and circuit theory (see i.e. Lumia et al., 2023). To prioritise ecological corridors, graph-theoretic metrics can be applied across a ‘landscape graph’, where patches (SACA1 areas) are nodes and areas of connectivity are edges (Urban and Keitt, 2001; Theobald, 2006; University of Lleida, 2007; in Hilty et al.2020).

“A Least-Cost-Path is defined as the pathway that offers the least resistance to an animal moving from one patch to another (Cushman et al., 2013) and is represented as the linear element (least-cost pathway) that connects two patches.” (Lumia et al., 2023)

With the LCP analysis it is possible to connect core areas (see section 6 Catalogue of GBI typologies) by the minimum cost path, taking into consideration landscape characteristics. Within the PlanToConnect project, the considered landscape characteristic will derive from the Continuum Suitability Index (CSI), because it rates natural and near-natural GBI elements as highly permeable.

Therefore, the least cost path tends to follow GBI elements and tries to avoid landscapes with a strong anthropogenic influence. LCPs with few and minor anthropogenic barriers can be considered as existing corridors, which have potential for protection by spatial planning.

In case that an LCP passes through anthropogenic landscape, it was evaluated:

1. if the barriers can be theoretically removed, and a corridor can be delineated and safeguarded by spatial planning, or
2. if the potential corridor must be dropped from the network.
3. the corridor could be slightly adapted/ moved through adapting the resistance model.

For specifications, please see section 3.4.2, Refinement of the network.

The potential linkages are prioritized by criteria for intervention priorities, according to the objectives of priority connectivity areas at various levels (see section 2.1).

3.2 Creation of network components/ sub- graphs

To run a model for an ecological network by the LinkageMapper tool including the total amount of SACA1 areas would exceed existing time and data storage resources.

A macro-regional model needs to prioritize important core areas, which should be connected. The size and proximity of SACA1 areas were considered as the most important criteria on this level for prioritizing the investigation of potential linkages. SACA1 areas <100ha were excluded from important core areas to connect. These excluded SACA1 areas were considered as steppingstones.

To simplify the model and to further reduce the number of SACA1 areas, "network components" were created by grouping SACA1 areas >100ha that are located in close proximity to each other. It was assumed, that these network components can be connected easier by intervention measures, which was confirmed in the barrier analysis afterwards (see section 4).

Therefore, SACA1 areas below 2.5 km linear distance to each other were grouped to "network components". Those of a total size smaller than 300 ha, were not considered as important elements to connect with regional linkages because of too extensive calculation times (see section 3.4.1 Test runs). For further details to the data processing for network components, please see annex 2.

SACA1 areas, located in large lakes, >300ha, were excluded from the model of ecological linkages. Exceptions are the wide Wetland of the Natura2000 site Camarge in France, Bohinji lake in Slovenia, Lac de Coiselet, lakes in the Natura2000 sites "Gorges de la Loire" and Gorges de la Loire aval, as well as Lac de Vouglans.

After the definition of these components, a barrier analysis was conducted to verify if such components are interlinked with GBI elements and therefore functioning. The barrier analysis revealed only 2 motorway barriers and 6 settlement barriers (see section 4 Barrier Analysis).

3.3 Creation of the resistance surface

The resistance raster was created by transposing the values from the Continuum Suitability Index (CSI) from ALPBIONET2030 (Lüthi & Costes, 2019).

$$\text{RES}_{\text{lin}} = 10 - \text{CSI}$$

Two test runs with different scales of the resistance values (0-100 and 0-1280) were made for macro-regional east- west connections.

The first resistance raster was assumed by a geometric sequence of numbers (RES geom) with a maximum resulting scale value of 1280.

General formula for a geometric sequence:

$$b_n = b_1 q^{n-1}$$

Formula used for the test run:

$$\mathrm{RES}_{geom} = 5 * 2^{RES_{lin}-1}$$

The second test run was done with an exponential transformation of linear resistances (RES $_{\text{exp, 100}}$) with a maximal scale value of 100 according to (Lüthi & Costes, 2019):

Exponential transformation of linear resistances:

$$RES_{exp} = e^{k*\,RES_{lin}}$$

where

$$k = \frac{\ln(scale)}{RES_{lin,max}}$$

where scale is the maximum value of the exponentially transformed resistance surface and $\text{RES}_{\text{lin,max}}$ is the maximum value of the linear resistance surface.

(Lüthi & Costes, 2019 based on Koen et al 2012 and Spear et al. 2010)

The results showed that the test run with a resistance raster of 0-1280 is more appropriate than resistances of 0-100 because SACA3 areas and other resistances along the paths are better avoided by least-cost paths and the corridor's width is more precise. It was visible, that a resistance raster with a maximum scale of 0-100 created very similar least-cost paths, but it comprises the risk of creating some linear corridor possibilities. Also, the analysis of the DinAlpConnect project showed that a low resistance raster range of 0-100 is resulting in linear least cost paths (Laner et al. 2022). Resistance values of 1-1000 and 1-2000 have been used in studies with highly similar approaches (Zou & Song 2021, Giombini et al. 2022).

It was decided to follow the ALPBIONET2030 approach with a maximum resistance value of 1.500 to be coherent with the test run of the geometric sequence and the exponential transformation of linear resistances.

Table 5: CSI values and transposed resistance values

CSI value	RES $_{lin}$	RES $_{geom}$	RES $_{exp, 1000}$	RES $_{exp, 1500}$
1	9	1280	1000	1500
2	8	640	464	666
3	7	320	215	295
4	6	160	100	131
5	5	80	46	58
6	4	40	22	26
7	3	20	10	11
8	2	10	5	5
9	1	5	2	2
10	0	3	1	1

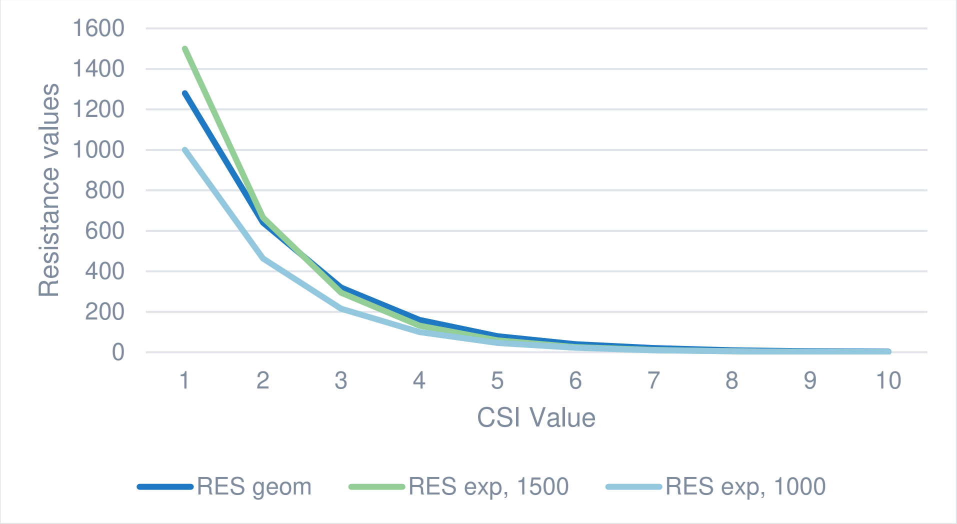


Figure 5: Comparison of resistance raster values

The ALPBIONET2030 project decided to exclude the fragmentation indicator (FRA) for the definition of the resistance raster, which the partners did not consider to be fair across regions. Considering the macro-regional scale in ALPBIONET2030, this did not influence the result very much. For the PlanToConnect GIS model, the fragmentation layer is considered for the overall resistance, because it reflects the density of roads to be crossed, which influences the cumulative resistance values of the least-cost-path.

The resistance raster was transferred from WGS84 Web Mercator to the ETRS89 LAEA coordinate system (EPSG 3035) because the Mercator projection is not an equal-area projection, which can lead to incorrect surface area calculations. The ETRS89 LAEA instead is a projected equal-area coordinate system commonly used for European wide datasets. The transformation led to a raster size of 50x50m instead of 100x100m.

3.4 Calculating Least-Cost-Paths as potential ecological linkages

The Least Cost Paths were calculated with the LinkageMapper tool in ArcGIS Pro by a stepwise approach.

3.4.1 Test runs

The first test run follows the approach of considering all 751 SACA1 area components >100ha and reducing the number of linkages by a maximum Euclidean distance of 50km. The second test runs followed the opposite approach of considering a reduced number of SACA1 area components according to a minimum size of 300ha and keeping a high number of long-distance linkages, limiting the maximum Euclidean distance to 90km.

The first test run resulted in 2.382 possible linkages and exceeded feasible computing times, the second one resulted in 1.428 adjacent core pairs to process.

The decision was made to consider only components of SACA1 areas with a minimum size of 300 ha. This allowed for a feasible processing of the large study area and to focus the analysis on those SACA1 areas that are more relevant at a wide transboundary scale.

In a European perspective, this can be seen as a high level of detail. Carrao et al. (2020), which contributes to a coherent Trans-European Nature Network, defined the threshold of a minimum surface area of 3.500ha for core areas referring to processing reasons. At the other hand side, it is recommended to consider also smaller areas in ecological network planning activities on local scale.

Parameters of GIS model conducted:

- Network Adjacency Model: 'Cost-Weighted & Euclidean',
- Drop Corridors that Intersect Core Areas: 'true',
- Maximum Number of Connected nearest neighbours: 'Unlimited',
- Nearest Neighbour Measurement unit: 'Cost-Weighted',

- Connect Neighbouring Constellations: 'true',
- Truncate Corridors: '30000' (30 km),
- Bounding Circles Buffer Distance: '20000' (20km)
- Maximum Cost-Weighted Corridor Distance: unlimited
- Maximum Euclidean Corridor Distance: unlimited
-

To save computing time and storage, a visual screening of the network was made, searching for linkages between two SACA1 areas, which will pass through a third SACA1 area. These linkages were set to “not active” in the Linkage Mapper tool, which means the Least cost path will not be mapped. Linkages > 40km were checked one by one, linkages <40km were checked sporadically.

Only one potential linkage has a Euclidean distance, longer than 100km, a second one was added manually after the refinement of the network for a river corridor.

3.4.2 Refinement of the network

A visual interpretation of each potential linkage was conducted, and it showed the need for improvements of the model. The first test run resulted in Least-Cost-Paths (LCPs) that were unrealistic to restore in some detailed situations. Some calculated potential linkages were passing through settlement areas, high altitudes, large lakes, or vast intensive agricultural areas. The biological value and feasibility of implementation of such least-cost-paths were questioned by the project partners. Therefore, corrections were made for the criteria settlements, large lakes, and some topographic characteristics regarding height and slope. This methodology is coherent with the creation of SACA2 areas (Ecological Intervention Areas for ecological connectivity) in the ALPBIONET2030 project (Lüthi & Costes, 2019).

For the refinement of the network, settlements were given the highest resistance value of 1.500, because there is a very low probability that existing buildings will be displaced because of the needs for ecological connectivity. This is coherent with the ALPBIONET2030 methodology for SACA2 areas, where SACA3 areas (barriers) were totally excluded as potential connecting elements (Lüthi & Costes, 2019). For this modification, a 10x10m dataset from the ArcGIS Living Atlas of the World, based on Sentinel-2 Land Use/Land Cover data was used and integrated in the 50x50m resistance raster (Esri, 2022).

Large lakes bigger than 300ha were excluded from the resistance raster by the assignment of “No data” values for the pixel values. This is coherent with the methodology of the SACA2 calculation in ALPBIONET2030 (Lüthi & Costes, 2019). This means, that least cost paths and corridors will not pass through these large water bodies. The needed geographical data were taken from the European Global Map (EuroGeographics, 2022).

Project partner’s and observer’s feedback on the low utility of corridors crossing high altitude areas and steep rocky slopes were taken into consideration in the resistance raster. Topographical barrier effects for a variety of species were integrated in the resistance raster, using the European Digital Elevation Model (EU-DEM), version 1.1 of the EEA 2020. In the

ALPBIONET2030 project the lowest suitability value for altitude in the calculation of the CSI was 2.900 m a.s.l., the second lowest was 2.750 m a.s.l., and areas above 2.500 m a.s.l. were excluded from all SACA2 areas in a second step. Therefore, these values were assigned also here to be consistent. The resistance value 131 corresponds to a resistance of a moderate barrier effect (CSI=4), while the value 58 corresponds to a resistance of a low barrier effect (CSI=5). (Lüthi & Costes, 2019)

Areas with following topographic characteristics were given a higher resistance:

Table 6: Additional resistance values

Characteristics	Resistance values
Steep slopes > 60°	666
Steep slopes > 65°	1500
Altitude >2900 m.a.s.l.	131
Altitude 2750-2900 m.a.s.l.	58
Altitude 2200-2750 m.a.s.l.	26

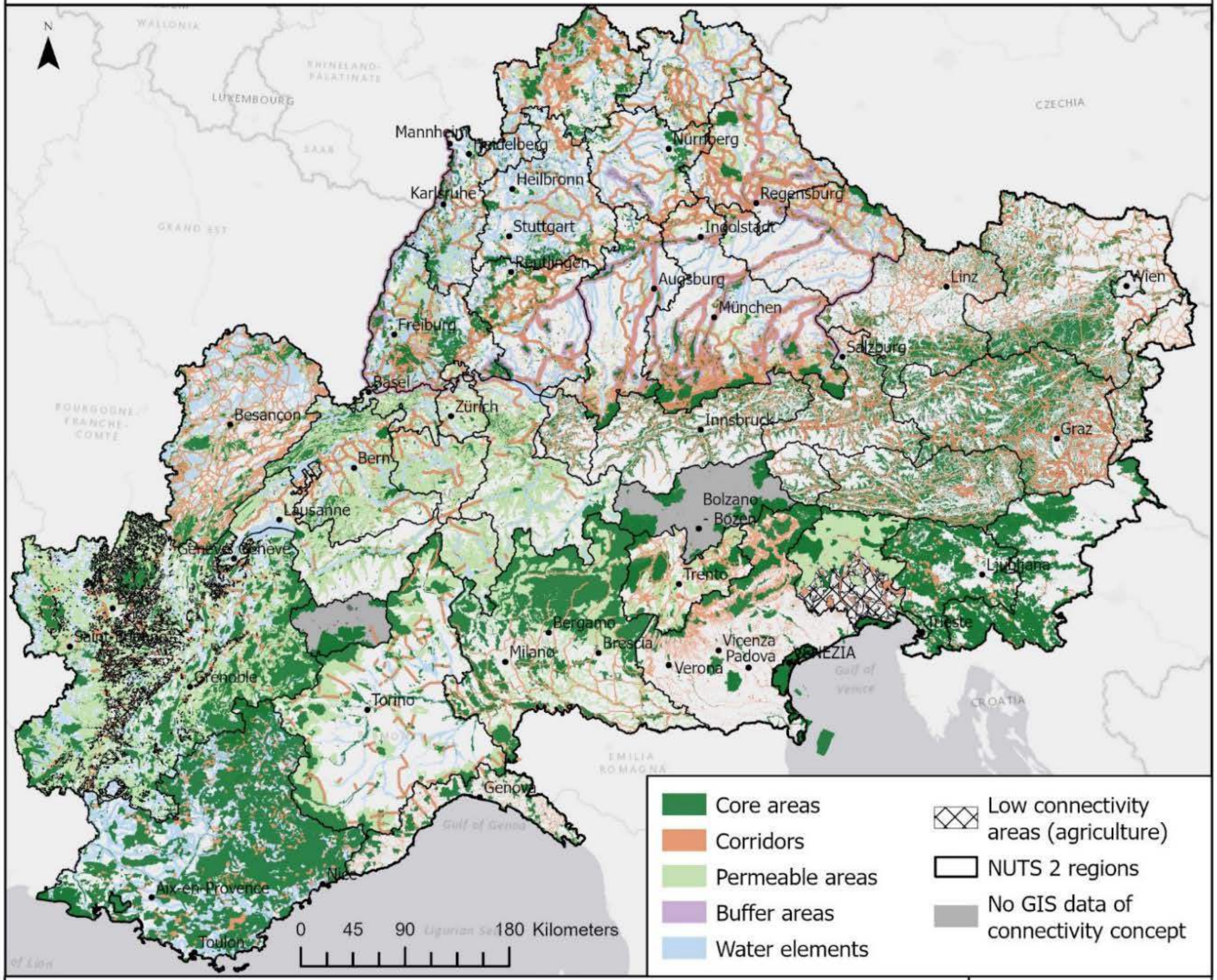
To verify that the potential linkage, calculated by the Linkage Mapper tool, has a feasibility for restoration measures and an ecological function, the resulting potential linkages were cross-checked with existing national ecological connectivity concepts. If a national concept was not existing, regional concepts were taken to proof the feasibility of the calculated corridor:

- Austria: The potential ecological corridors were cross-checked with the “Map of the most important habitat corridors in Austria” (Lebensraumvernetzung.at, 2022).
- France: The green and blue network *(fr. Trame verte et bleue)* was used for the verification. (Inventaire National du Patrimoine Naturel, 2023) The layer corresponds to a selection for three regions: Auvergne-Rhône-Alpes, Bourgogne-Franche-Comté and Provence-Alpes-Côte d'Azur. The selection was based on the polygons layer "couche nationale des corridors surfaciques".
- Germany: Selected elements from the national concept for green infrastructure (*germ. Bundeskonzept Grüne Infrastruktur) (*Heiland et al., 2017) was taken to verify the GIS model (National Office for Nature Protection, 2023).
- Italy: The national concept for Italy elaborated in 2002 neither had a high level of detail, nor it was legally implemented. Therefore, concepts of the regional landscape plans were collected for Friuli-Venezia-Giulia, Liguria, Lombardy, Piedmont, Trentino and Veneto. No regional concept was found for the Aosta Valley and South Tyrol. Since South Tyrol is a pilot site within the PlanToConnect project, it was possible to discuss the feasibility of potential corridors with observers from provincial planning offices.
- Liechtenstein: due to its small surface extension, Liechtenstein was not considered in the cross-checking procedure.
- Slovenia: The ecological connectivity datasets provided by the guidelines of the national spatial planning concept of Slovenia was taken for the cross-checking.

- Switzerland: The ecological network concept on the national level of Switzerland (BAFU, 2022 [1] & [2]), which has a high level of detail, provided necessary information.

For details see section 9 on GIS data sources. An example of overlapping the Austrian national concept with resulting potential linkages is provided in Figure 24: "Comparison between the PlanToConnect structural model at Alpine level and the national connectivity concept of Austria".

Ecological connectivity concepts at national and regional levels* in the EUSALP macro-region



*National concepts are shown for Austria, France, Germany, Switzerland and Slovenia. Regional concepts are mapped only for Italy. Not all levels of detail are included.

Sources: Austria: Lebensraumvernetzung.at. France: INPN - Trame verte et bleue. Germany: Data request to the National Office for Nature Protection on Bundeskonzept Grüne Infrastruktur. Italy: Regional geoportals (Geoportale della Lombardia, Il Geoportale della Regione del Veneto, WebGIS PAT, Geoportale Alto Adige, Geoportal Regione Liguria, Geoportale Piemonte, Eaglefvg). Switzerland: bafu.admin.ch. Slovenia: data request to University of Ljubljana, Biotechnical Faculty, 2021. Basemap: Light grey canvas from ArcGIS Pro based on ESRI, HERE, Garmin, USGS.

Eurac Research, Institute for Regional Development
Authors: Vitangeli V., Laner P.,
December 2023

Figure 6: Regional and national ecological network concepts in the EUSALP area

After the verification with the national and regional concepts, a refinement of the network had to be made by manual modifications. In total, 139 potential linkages were deleted manually, and 32 linkages had to be added.

Most of the linkages evaluated as “impossible to implement” were longer than 13 km, which corresponds to 90% of all deleted linkages. Only 14 deleted potential linkages were shorter, which is 3% of all potential linkages.

Table 7: Reasons for deleting potential linkages from the network per country

Main reason for deleting the potential linkage from the network	**AT**	**FR**	**DE**	**IT**	**SI**	**CH**	**Trans-national**	**Sum**
National or regional ecological network plans are not considering this linkage	2	3	45	3			4	57
Long distance is passing through intensively used areas, without steppingstones	4	8	13	10			1	36
Continuous settlement structure or SACA3 area, not restorable	7	11	1	1	1		3	24
Linkage passing through a large lake				6		3	2	11
Linkages passing through very high altitudes						5	2	7
other			1	1			2	4
Sum	13	22	60	21	1	8	14	139

Especially river courses were not followed by the least-cost-path calculations of the Linkage Mapper tool. Rivers are mostly not part of SACA1 areas because of their small areal extension and the remaining SACA1 areas on river elements are mostly not adjacent. Therefore, the Linkage Mapper tool has difficulties to identify rivers as potential corridors. To represent rivers, which were also highlighted in national and regional concepts as ecological corridors, selected steppingstones on rivers with lower minimum size than 100ha were inserted as SACA1 areas to represent the river as a connecting element in the network and to integrate it into the overall network model.

Additionally, some smaller modifications of the resistance raster were made for the Po River, the Ticino River, the Piave River, the Illasi torrent (Veneto), and the Adda River in Italy, to align the linkages to the regional concepts. Additional modifications in the resistance raster were done for the Inn valley in Tirol (AT) increased the coherency of the model with the national concept.

3.4.3 Result of a potential ecological network

The result of a potential ecological network is showing 953 potential regional ecological linkages in the EUSALP area, which are between 2.6 and 163.7 km long, with a median length of 15 km. All regional potential linkages together have a total length of 21,652 km.

The linkages are passing through smaller SACA1 areas between 0.4 and 300 ha, which can be considered as steppingstones. In total, more than 50% of these steppingstones are included as connecting elements by the corridors. Summing up all SACA1 components and the areas of steppingstones on the identified potential linkages, it turns out that the model is only excluding 1,96 % of all SACA1 areas. Some SACA1 areas near Marseille and one on the lake Constance (0,13% in total) are not connected due to highly fragmented characteristic of the surrounding area.

Linkages crossing high altitude areas:

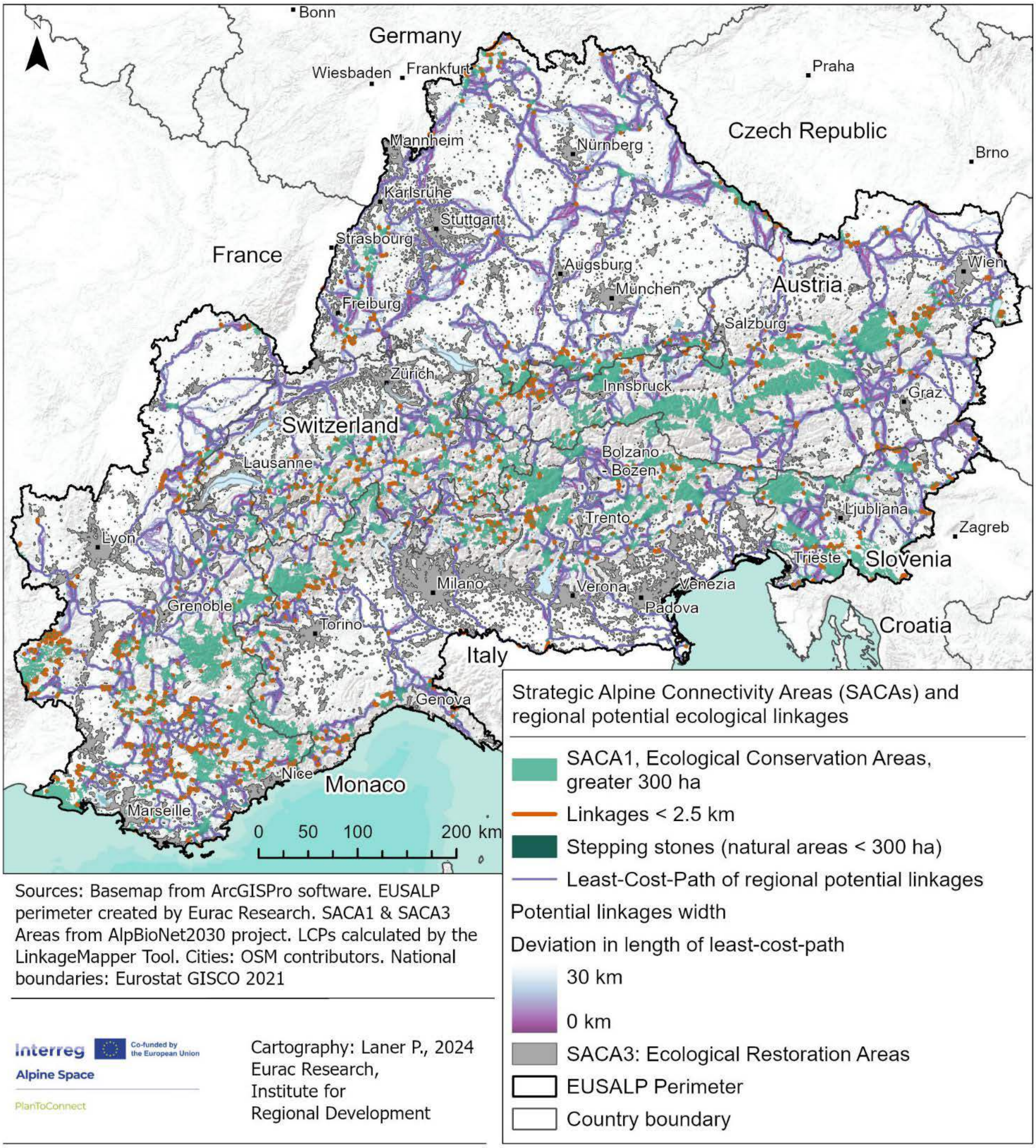
With the refinement of the network, the ecological connectivity model tries to avoid high-altitude areas, but this does not mean that all areas above 2.900 m sea level are completely excluded: A lot of SACA1 areas are on such high altitudes and the model still includes four potential linkages crossing very short passages of areas above 2.900 m. The calculation dropped only approximately 15 of 1089 linkages from the model because of high altitudes, in other cases the linkages are just taking a path on a lower altitude level, which is the focus of the PlanToConnect project. It is suggested to analyse the connecting function of such areas case by case, with species- based models e.g. In high altitude areas species are very specialized and adapted to their environment, but the limited number of species living at these altitudes does not mean that there is low importance for the ecosystem. The habitat of some umbrella species, like the chamois e.g., is including such high-altitude areas. These areas of the Alps are affected by anthropogenic interventions, as for example ski resorts or hydropower plants, that can cause negative effects on the whole ecological system.

Remaining inconsistencies of the model:

Although a detailed network refinement was conducted, smaller inconsistencies are present. Some least-cost-paths in the Po Valley do not follow expected river corridors, but in some parts, it leaves the river corridor for a certain distance and cross through agricultural land, while the section of the river corridors represents an alternative route. In some cases, this has been caused by the higher resistance values given to settlements, which represent a barrier on the river corridor. Here, more detailed studies on the landscape permeability must be conducted, possibly with target species.

A major inconsistency can be identified in Germany, in the north of Lake Constance, where linkages are leading to minor SACA1 areas and ending there (See Annex 4), while the ALPBIONET2030 project is defining a major important connectivity area that connects the inner with the outer Alpine Space. Here is the question if the Concept for Green and Blue Infrastructure of Germany should consider potential ecological connections from the Danube

River between Munderkingen and Riedlingen (Natura 2000 site DE7823341) and the area around Natura 2000 site “Federsee und Blinder See bei Kanzach” (DE7923341).



Sources: Basemap from ArcGISPro software. EUSALP perimeter created by Eurac Research. SACA1 & SACA3 Areas from AlpBioNet2030 project. LCPs calculated by the LinkageMapper Tool. Cities: OSM contributors. National boundaries: Eurostat GISCO 2021

Cartography: Laner P., 2024
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Institute for
Regional Development

Figure 7: Potential ecological network

3.5 Spatial criteria for a coherent network

To create a coherent ecological network is a major objective on European level. Therefore, there is a need to know which are the most important linkages that keep the network on the territory of the EUSALP macro-region together. There exist several quantitative but also qualitative approaches to answer this question.

On one hand there are quantitative evaluations, like for example the minimum spanning tree and the current flow centrality. The minimum spanning tree is based on network theory based on cost- weighted distances of the least-cost-path, while the current flow centrality is mainly based on electric circuit theory.

On the other hand, quantitative evaluations on priority linkages by expert opinions are a very useful tool to generate consensus and a coherent picture. Fortunately, expert workshops were already conducted by the ALPBIONET2030 workshop and produced valuable results, that can be used in the modelling.

3.5.1 Minimum spanning tree

The minimum spanning tree is a second option to create a coherent network. The minimum spanning three constitutes the network of shortest linkages that connect each core area, with the objective to keep all core areas connected and to represent a complete network. It is used in landscape connectivity modelling for a long time (Urban, D. and Keitt, T. (2001).

It was calculated with the “build network and map linkages” - Tool within the LinkageMapper toolbox developed by McRae and Kavanagh (2011), using the “Prune Network” options (step 4). The maximum number of connected nearest neighbours was set to one and the nearest neighbour measurement unit was set to the cost-weighted distance. This means, that each SACA1 area was connected to its nearest neighbour and in a second step it was connected to disjunct clusters (constellations). This second step “connects clusters of core areas together, starting with the closest, until all clusters are connected” (ibid.).

Almost half of the potential linkages (465 out of 953) were identified as important for the network in this way, 338 linkages connect nearest neighbours which create constellations or sub-graphs of the whole network, and 127 potential linkages connect these constellations through each other.

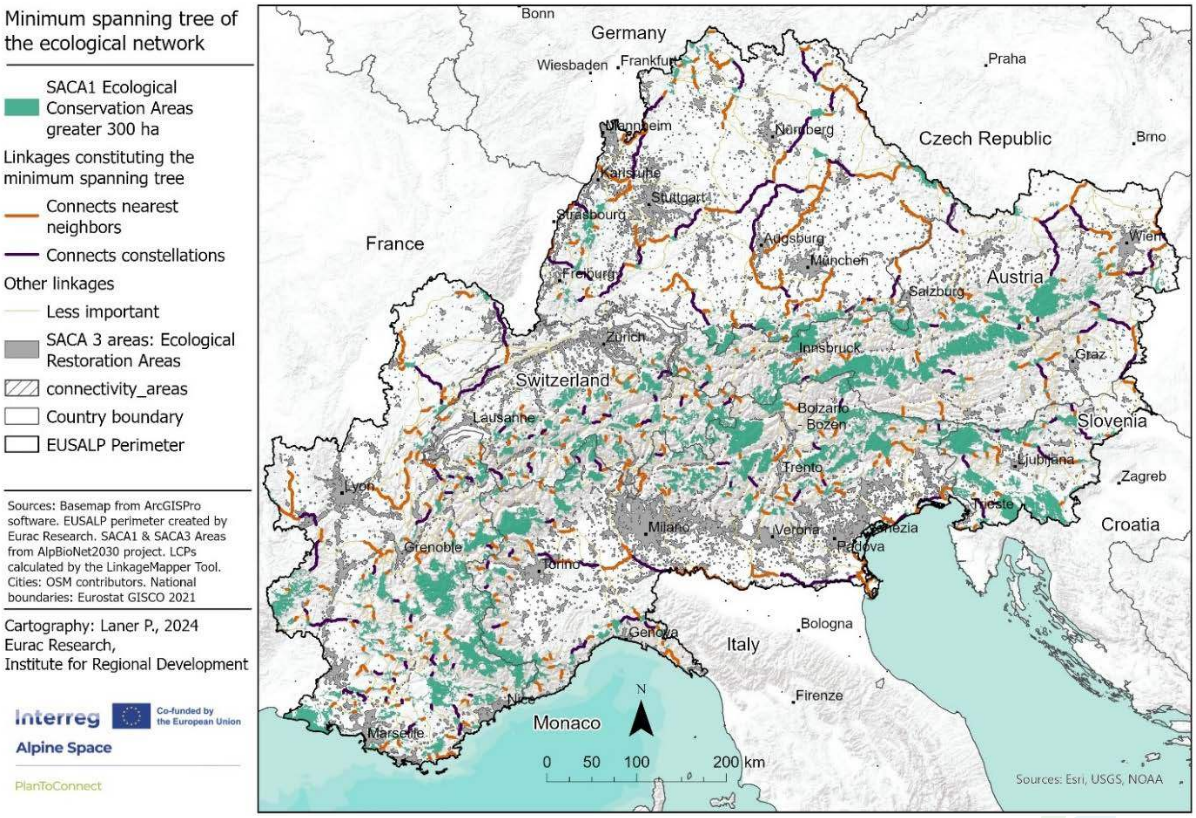


Figure 8: Minimum spanning tree

3.5.2 Centrality

The current flow centrality is a measure of how important a link or core area is for keeping the overall network connected. A higher score means the loss of the linkage would disconnect a high number of core areas from the rest of the network. It was calculated with the Centrality Mapper Tool within the LinkageMapper toolbox developed by McRae and Kavanagh (2011). The values were classified into three groups of high, medium, and low centrality, to define intervention priorities and to improve the readability.

In statistical terms the classes were set according to quantiles. The upper tertile starts approximately from the average value of the current flow centrality. In other words, most of the values above average are classified as potential linkages with a high centrality.

From a visual interpretation, it is visible, that linkages with a medium centrality play an important role to connect the inner alpine network with other areas, outside the Alpine Space.

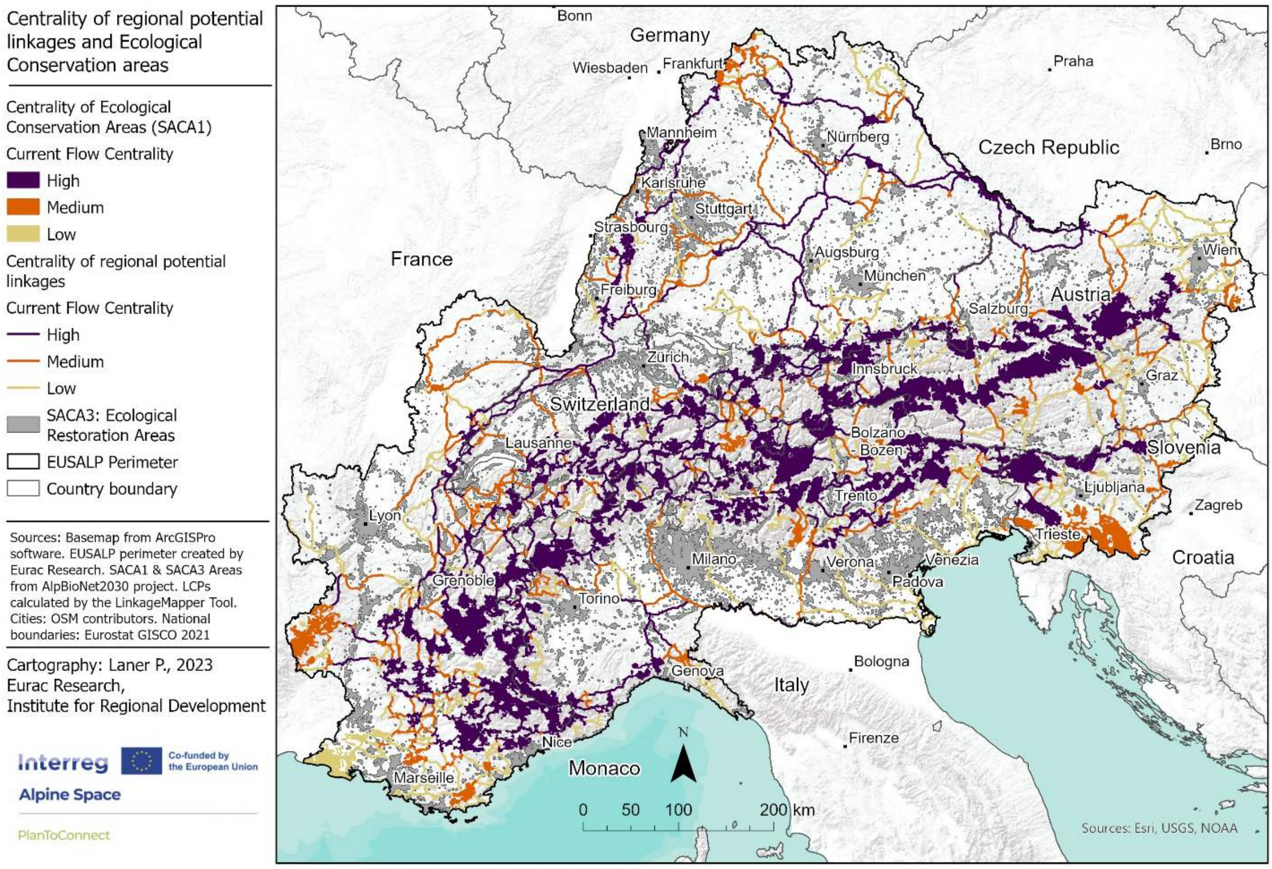
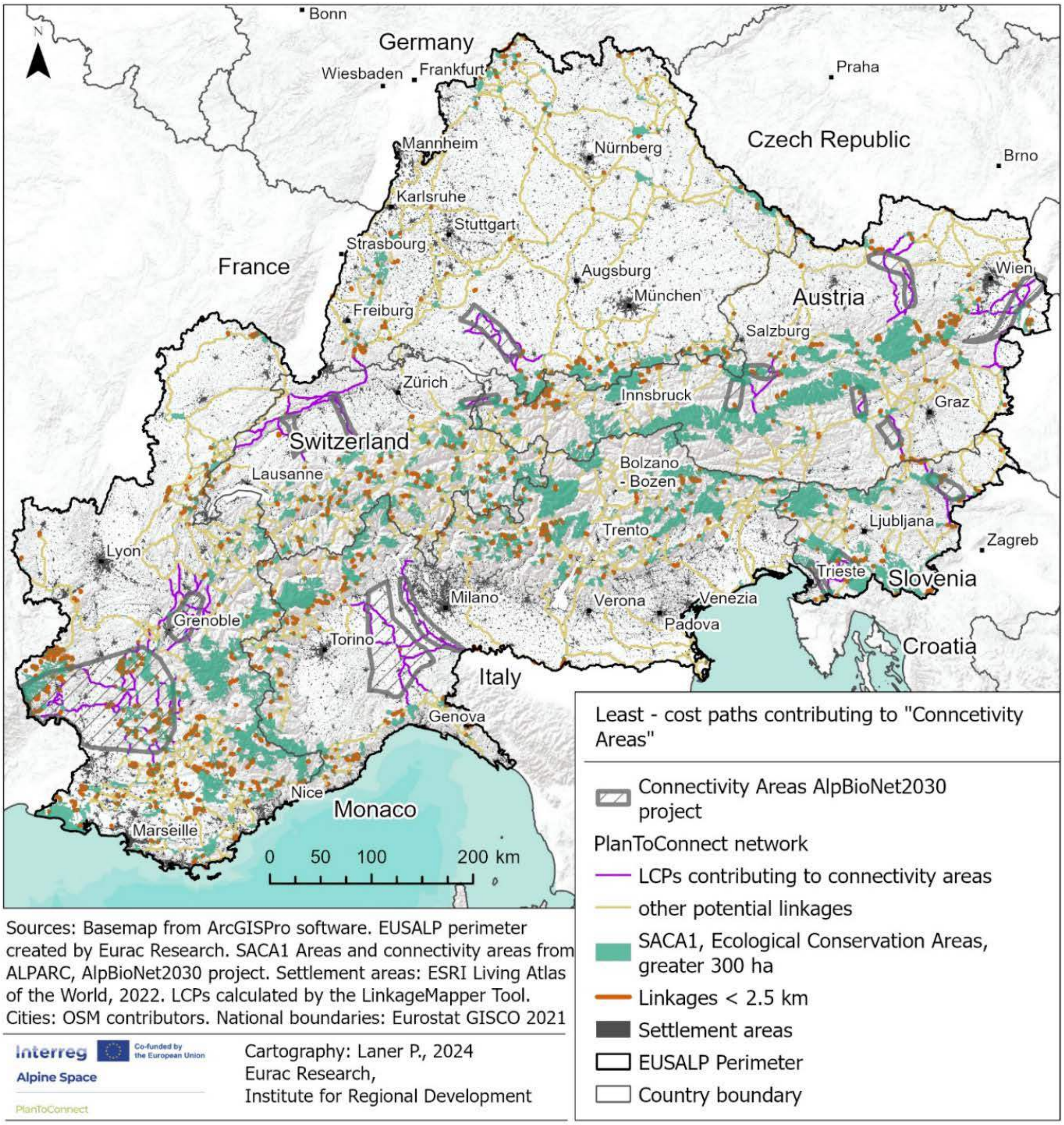


Figure 9: Current flow centrality of regional potential linkages and Ecological Conservation Areas

3.5.3 Connectivity areas between outer and inner Alpine Space

The Connectivity Areas from the Interreg Alpine Space ALPBIONET2030 project were taken to filter important linkages which connect the inner Alpine Space with other mountain ranges or other main wildlife sites close to the Alps (definition see section 1.1). For the PlanToConnect project, potential linkages which overlap with connectivity areas, or which are in a wider distance of approximately 5 km to the connectivity areas were chosen.



Sources: Basemap from ArcGISPro software. EUSALP perimeter created by Eurac Research. SACA1 Areas and connectivity areas from ALPARC, AlpBioNet2030 project. Settlement areas: ESRI Living Atlas of the World, 2022. LCPs calculated by the LinkageMapper Tool. Cities: OSM contributors. National boundaries: Eurostat GISCO 2021

Cartography: Laner P., 2024
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Figure 10: Least-cost-paths contributing to connectivity areas

Excursus regarding climate change aspects

Within the Interreg Alpine Space LUIGI project, the Agricultural Institute of Slovenia provided condensed information regarding ecological connectivity and climate change.

“Climate change will influence species […] distribution (Bellard et al., 2012), resulting in extinction for those unable to adapt. […] (Thomas et al., 2004). On the basis of mid-range climate-warming scenarios, 15-37% of species will be committed to extinction by 2050.

One of the ways species are adapting to climate change is by shifting their range (Hughes, 2000). Due to large differences in elevation in mountain regions, the obvious shift is expansion to higher elevations, as has been shown in models and confirmed in reality (Chen et al., 2009; Pauli et al., 2007). Ecological connectivity is crucial for enabling these shifts.

Models of climate change threats to European plant species showed a greater habitat loss for species distributed at higher elevations (Engler et al., 2011; Thuiller et al., 2005). Depending on the climate scenario, (Engler et al., 2011) found 36–55% of alpine species, 31–51% of subalpine species and 19–46% of montane species will lose more than 80% of their suitable habitat by 2070–2100.” (Bertoncelj & Rekič, 2020)

Recently, Vitasse et al. (2021) investigated elevational shifts of plants, animals and fungi under climate change in the European Alps and “*provided evidence that spring phenology has been shifting earlier during the past four decades and distribution ranges show an upwards trend for most of the taxonomic groups*”. Considering a high number of plants, animals and fungi species, it was found out that there was a general shift upslope in their distribution with similar pace, on average +25 m per decade. However, the differences among taxa were substantial (ibid.).

Considering these findings, it is assumable, the inner Alpine Space (Alpine Convention perimeter) could become a climate refugium. Taking into account climate change aspects at Alpine-wide level, therefore it is important to connect the outer alpine flatland areas with the inner Alpine Space that consist in mountainous topography. This is in line with the objective to counteract the island effect of the Alps when it comes to the prioritization of linkages (see section 5).

4 Barrier and bottleneck analysis

In general, the most important areas with a high barrier effect are highlighted by the SACA3 areas (Connectivity Restoration Areas), identified by the ALPBIONET2030 project. With the analysed potential regional linkages in this project, it is now possible to see where the most important passages for restoration measures are located. Overlapping LCPs with SACA3 areas, it results that 91 linkages are passing through SACA3 areas. There are 160 sections of LCPs passing through SACA3 areas with an average length of approximately 1.5 km, varying between 13 to 6,869 meters. In total, 238 km of LCPs pass through SACA3 areas, which corresponds to only 1% of the total length of the network (21,652km).

The detailed barrier analysis focuses on settlement barriers, motorway barriers, and solar panel fields because the development of these sectors can be strongly influenced by land use planning. The sector of agricultural areas is not a main pillar in the PlanToConnect project, but important for landscape planning. Passages of intensive agricultural areas will be included in the analysis of synergy effects and conflicting uses (Activity 1.2). Regarding The alpine wide structural model for ecological connectivity is not made for aquatic species, therefore hydropower plants were not considered in the barrier analysis.

According to an Austrian draft guideline on evaluation of ecological corridors, the dimensions of corridors and the land cover/ land use characteristics of the corridors are important for the functionality for wildlife species (Leitner et al., 2022). Regarding the dimensions, a trans-regional corridor should have a minimum width of 800m so that it can be used by disturbance-sensitive wildlife species such as the red deer. Trans-regional corridors serve the “migratory needs and genetic exchange of wild animals”. Regionally important corridors should have a minimum width of 300 m, which is intended to ensure that wild animals with local knowledge can make a seasonal change.” A local corridor can have a width of 150m, which should ensure daily movements (Leitner et al., 2022).

These relevant dimensional criteria of regional important corridors were applied to sub-graphs and Least-Cost-Paths in the PlanToConnect model.

Regarding land use characteristics, “*habitat corridors run in the forest or in open land (largely undeveloped area outside the forest). Rows of trees, hedges, wetlands with accompanying vegetation or fallow structures are regarded as favourable surface creation outside the forest in order to make the corridor more attractive. Otherwise, agricultural management is suitable as a corridor component, especially in the period with standing crops without barriers.”* (ibid.)

4.1 Settlement barriers and urbanisation threats

A settlement was defined as a built-up area of more than 0.5 ha, using the Esri Sentinel-2 10m Land Use/Land Cover dataset 2022, accessible from the Esri ArcGIS Living Atlas of the World. The Esri Land Cover dataset has a high resolution and distinguishes in an appropriate way built-up areas from sealed soil. The threshold of 0.5ha was set to exclude farms or small groups of farms in rural areas. The following example shows a minor group of farms next to a LCP, excluded from the settlement barrier effect.

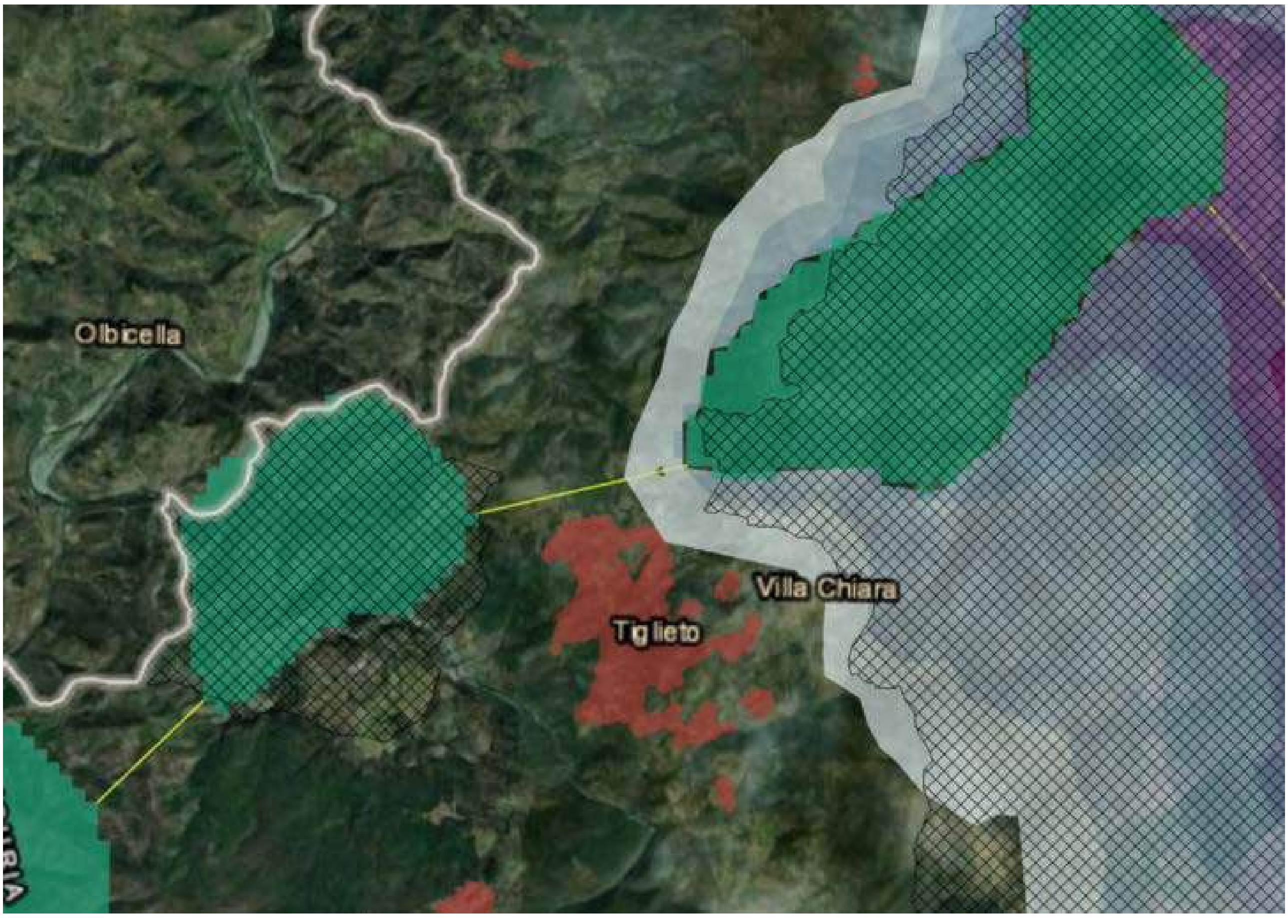
Picture 1: Settlements smaller than 0.5 ha excluded from the barrier effect

Other artificial land use types like mineral extraction sites were not considered in the evaluation.

4.1.1 Settlement barriers on subgraph distances (<2.5km)

Subgraph distances closer than 150m each side to settlement areas of more than 0.5 ha were selected and evaluated by a visual interpretation. Out of 183 subgraph distances, where settlement areas are in closer distance than 150m each side, only six represent a real closed settlement barrier and only 25 represent a bottleneck threatened by urbanization.

Situations, where the settlement area is not expected to close the corridor soon, were excluded from the urbanisation threat. The following example of SACA1 areas near the Italian village Tiglieto in Liguria should illustrate such cases in a more practical way. Tiglieto lies on a 300m broad linear green corridor between two SACA1 areas which are Natura2000 sites in distance of just 1.2 km to each other. However, the settlement structure seems not to be a barrier or a threat to the connection between the two SACA1 areas at the moment.



Picture 2: Settlement revealed in a 150m distance to the linear short-distance corridor, but without urbanisation threat.

4.1.2 Settlement barriers on potential regional ecological linkages

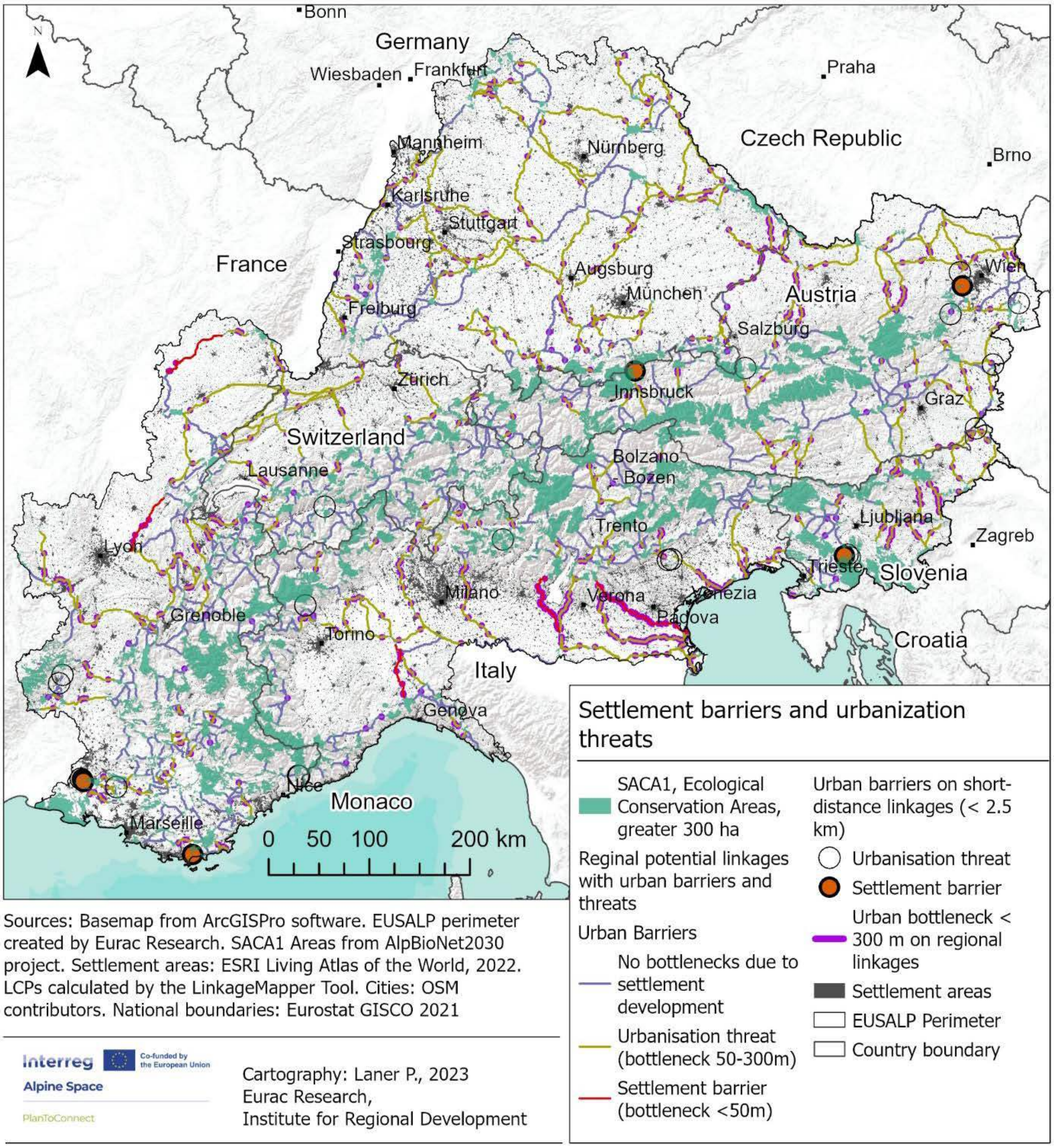
If a corridor is passing through a settlement gap, which is of less than 300 m distance, it was classified as a bottleneck due to settlement development. Due to the small distance of 300 m, it was assumed that these corridors are at risk of getting lost due to urbanisation.

A detailed analysis of the effective bottlenecks was made by excluding linkages where the least-cost-path is passing through areas in a greater distance of 300 m to settlements also considering a diagonal direction and by a visual interpretation of possible alternative routes of the LCP in ArcGIS Pro 3.2.0 (see picture 4). The results are showing that 309 potential ecological linkages are passing through 972 bottlenecks of less than 300 m due to settlement development. Such linkages, which could be threatened by urbanisation, represent one third of the total number of identified potential linkages.

This result highlights the importance of spatial planning for considering ecological connectivity in settlement development processes. Urbanisation threats appear mainly in the flatland areas of the outer Alpine Space, especially in the Po Valley (IT), in the centre of Slovenia, in the flatland areas of Upper and Lower Austria (AT), around Lyon (FR), and at the border between Austria and Germany. Often, bottlenecks due to urbanization occur along river corridors because settlements were placed on rivers due to its former importance as trade routes and have historically grown to major cities, creating bottlenecks for potential wildlife linkages nowadays. Green infrastructure along rivers results as important connecting elements in the Alpine - wide model.

In a second step, the effective settlement barriers were identified. For a regional corridor, the minimum width of a bottleneck must not be less than 50 metres. (Leitner et al., 2022) Using the same procedure as for the identification of bottlenecks, the analysis revealed 6 corridors that have a bottleneck of settlement barriers, which are smaller than 50m and therefore represent a real built-up barrier.

1. Industrial zones of Giovanni Quarena and Prevalle between Brescia and Garda Lake (IT) almost merged and are about to close the linkage between the Mountainous areas of Lombardy and the Chiese river.
2. A hydropower plant was revealed on the river Bormida di Spigno near Alessandria, Piedmont (IT).
3. The industrial zone Zermeghedo in the Veneto region (IT) is representing a settlement barrier between the Natura2000 site Colli Berici and the Lessinia regional parc.
4. Punta Gorzone near Chioggia (IT) is a settlement barrier between the Lagunes of Venice and Caleri.
5. The artificial riverbank of the Ain River near the city Pont d’Ain (FR) are revealed as a barrier.
6. The model revealed a settlement barrier for the river La Saone (FR). It has narrow artificial riverbanks near the city Gray.

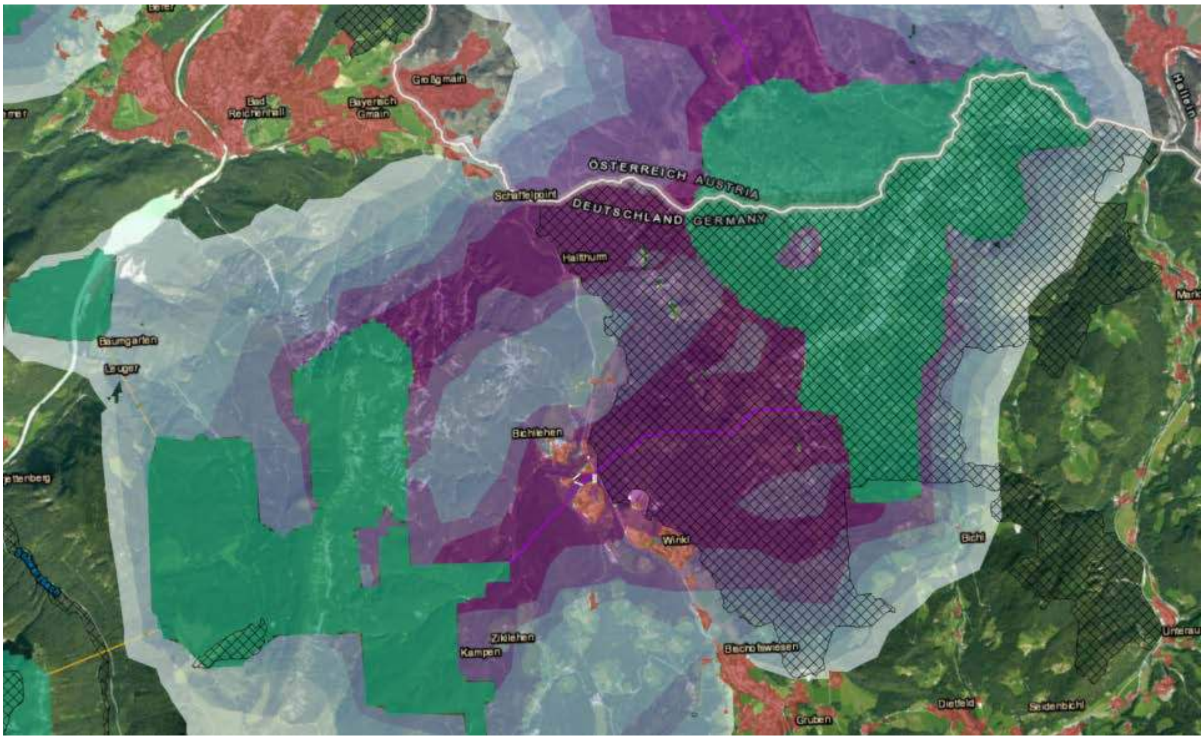


Sources: Basemap from ArcGISPro software. EUSALP perimeter created by Eurac Research. SACA1 Areas from AlpBioNet2030 project. Settlement areas: ESRI Living Atlas of the World, 2022. LCPs calculated by the LinkageMapper Tool. Cities: OSM contributors. National boundaries: Eurostat GISCO 2021

Cartography: Laner P., 2023
Eurac Research,
Institute for Regional Development

Figure 11: Settlement barriers and urbanization threats on regional and local potential linkages

Picture 3: Potential regional ecological linkage at risk by urbanisation in the pilot site of Sondrio



Picture 4: Corridor with urban barrier on Least-Cost-Path and second possibility without urban barrier

The image shows the example of a potential ecological linkage between the Natura2000 site Unterberg, and the Frechenbach river near Kampen, Berchtesgaden, Germany. The Least-Cost-Path is threatened by urbanisation, but there is a second possibility, far from existing settlements. The potential linkage was not classified as threatened by urbanisation.

4.2 Motorway barriers:

Intersections of the motorway transport system with the LCPs and subgraph- distances from the macro-regional model made it possible to identify specific locations of motorway barriers. Motorways were represented by data from the EuroGlobalMap 2022 (EGM 2022), excluding tunnels and motorway bridges. Only the location levels “on ground surface” and “unknown” were kept for representing real motorway barriers.

Table 8: Elements with following attributes from the Road – lines layer was selected:

Attribute name	**Location Level**	**Route Intended Use**
Short name	*LLE*	RTT
Data type:	Short integer	Short integer
Domain	Coded value	Coded value
Selected categories	***-32768 Unknown*** ***1 On ground surface***	**16 National Motorway**
Excluded categories	*-9 Underground (unknown level)* *-2 Underground (second level)* *-1 Underground (first level)* *2 Suspended or elevated (first level)* *3 Suspended or elevated (second level)* *9 Suspended or elevated (unknown level)*	-32768 Unknown 14 Primary route 15 Secondary route 984 Local route

4.2.1 Motorway barriers on subgraphs

The distances of 2.5km were part of the first barrier analysis. Motorways and urban areas were considered for a first evaluation.

Among 1.244 locations, where SACA1 areas are in proximity of 2.5km to each other, only two cases were found where the landscape is interrupted by a motorway. The search distance to identify motorways near the theoretical linkages was set to one kilometre.

The first case is located near the municipality Turtmann-Unterems in the canton Wallis, Switzerland, near the nature park Pfyn-Finges.

Here a SACA1 network component, which would have an area of more than totally 9.000 ha is interrupted by a relatively new motorway. There are little alternatives for wildlife passages because the tunnels of the motorways are constructed mostly to avoid settlement areas. Also, the railway line and the rectified river are creating substantial barriers.

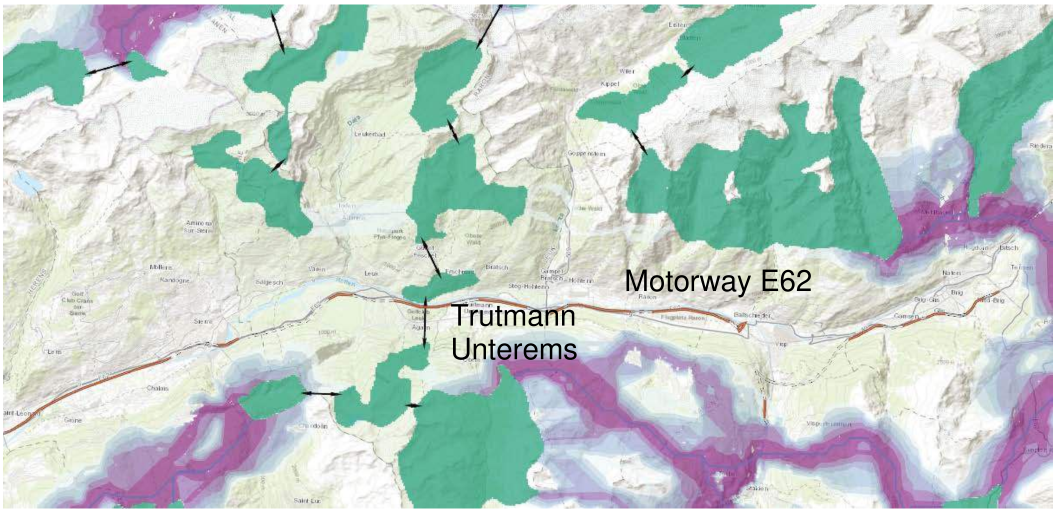


Figure 12: Motorway barrier on a potential corridor of <2.5km distance in Wallis

The second case is located in the Pongau district of the Federal State of Salzburg, Austria, approximately 8 km to the south of the village Golling an der Salzach. The area is fragmented by a motorway, a railway line and a mineral extraction site.

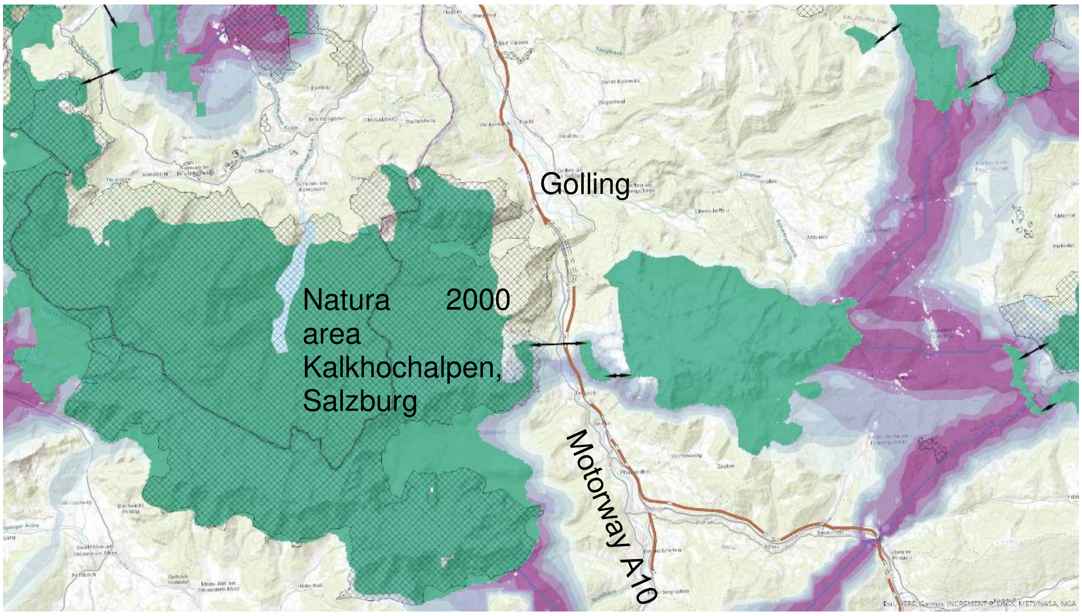


Figure 13: Motorway barrier on a potential corridor of <2.5km distance in Salzburg

4.2.2 Motorway barriers on least-cost paths of regional potential linkages

Regarding the regional potential linkages, 264 geographical motorway intersections were identified by the intersect function in ArcGIS Pro 3.2.0. Some of these locations include two potential linkages on the same crossing point, therefore 322 potential linkages are affected by motorway intersections in total. Each of these motorway intersections was verified by a visual interpretation with satellite images and Google Earth Pro 2022 in a second step. In this way, other motorway bridges, green bridges, tunnels, and smaller underpasses were identified which were not represented in the EGM dataset, categorizing the motorway barriers. Such possible wildlife passings were considered even though they were on an alternative route of the LCP or if they are in relatively close distance of 1-2 km to the geographical intersection identified by ArcGIS.

The rest of the motorway intersections should represent real physical barriers, but it is recommended to verify the motorway intersections by a field visit and by more detailed studies for selected species, to assure their functionality.

The degree of the barrier effect of identified motorway intersections can be put on a scale according to the type of infrastructure and its constructive elements found on the potential linkage.

Type of identified infrastructure	Barrier effect	Number
Tunnel	Very low	12
Motorway bridge	Low	58
Green bridge	Low to moderate	10
Underpass	Moderate	34
Motorway on ground surface, 2 lines	High	2
Motorway on ground surface, 4 lines	Very high	132
Motorway on ground surface, > 4 lines	Extremely high	16

In total, 155 linkages are intersecting with motorways placed on ground surface. Some motorway barriers intersect with two different potential linkages in the same location. France and Germany are the two countries with the most identified motorway barriers. In 39 cases, motorway barriers are located within or close to SACA3 areas.

Table 9: motorway barriers by country

Country	Number of motorway barriers
France	44
Germany	37
Austria	27
Italy	20
Switzerland	13
Slovenia	9
Sum	150

It is recommended to respect the guidelines for reducing the barrier effect of wildlife crossings for motorway intersections according to the Infrastructure & Ecology Network Europe[3] (IENE, 2022).

Examples of identified wildlife passings for each infrastructure type are shown on the following pages.

Motorway tunnels:

The example of the motorway tunnel near St. Andrä, in Carinthia (AT) shows a geographical intersection of the A2 motorway and a potential regional linkage, while the satellite imagery disproves the motorway barrier. The intersection is caused because the tunnel is not represented in the EGM dataset. The barrier effects of such cases can be evaluated as very low.

Picture 5: Motorway tunnel near St. Andrä, in Carinthia, Austria

Motorway bridges:

These motorway elements are adapted viaducts or landscape underpasses with a large structure, usually supported by pillars or arches (IENE, 2022). Major motorway bridges which are not represented in the EGM dataset mostly appear in cases of rivers or to overcome unregular ground levels in hilly or mountainous landscapes.

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[3] See the European Handbook for Identifying Conflicts and Designing Solutions: https://handbookwildlifetraffic.info/ch-7-solutions-to-reduce-transport-infrastructure-impacts-on-wildlife/7-4-reducing-barrier-effect-wildlife-passages/

The river represents a potential regional linkage (green line), which is not totally interrupted by the motorway.

Picture 6: The river represents a potential regional linkage (green line), which is not totally interrupted by the motorway.

The Least-cost-path is represented by the green line.

Picture 7: Motorway bridge of the E57 near Cerovec, municipality of Šentjur, Slovenia

Green Bridges:

In total, 10 green bridges were identified on the whole macro-regional ecological network. The existence of a green bridge confirms the functionality of the identified potential linkage.

This green bridge was identified on an alternative route of the least-cost-path.

Picture 8: Green bridge, so-called "Bärenbrücke", in Carinthia, Austria

The least- cost – path (green line) is passing 87 meters near the green bridge.

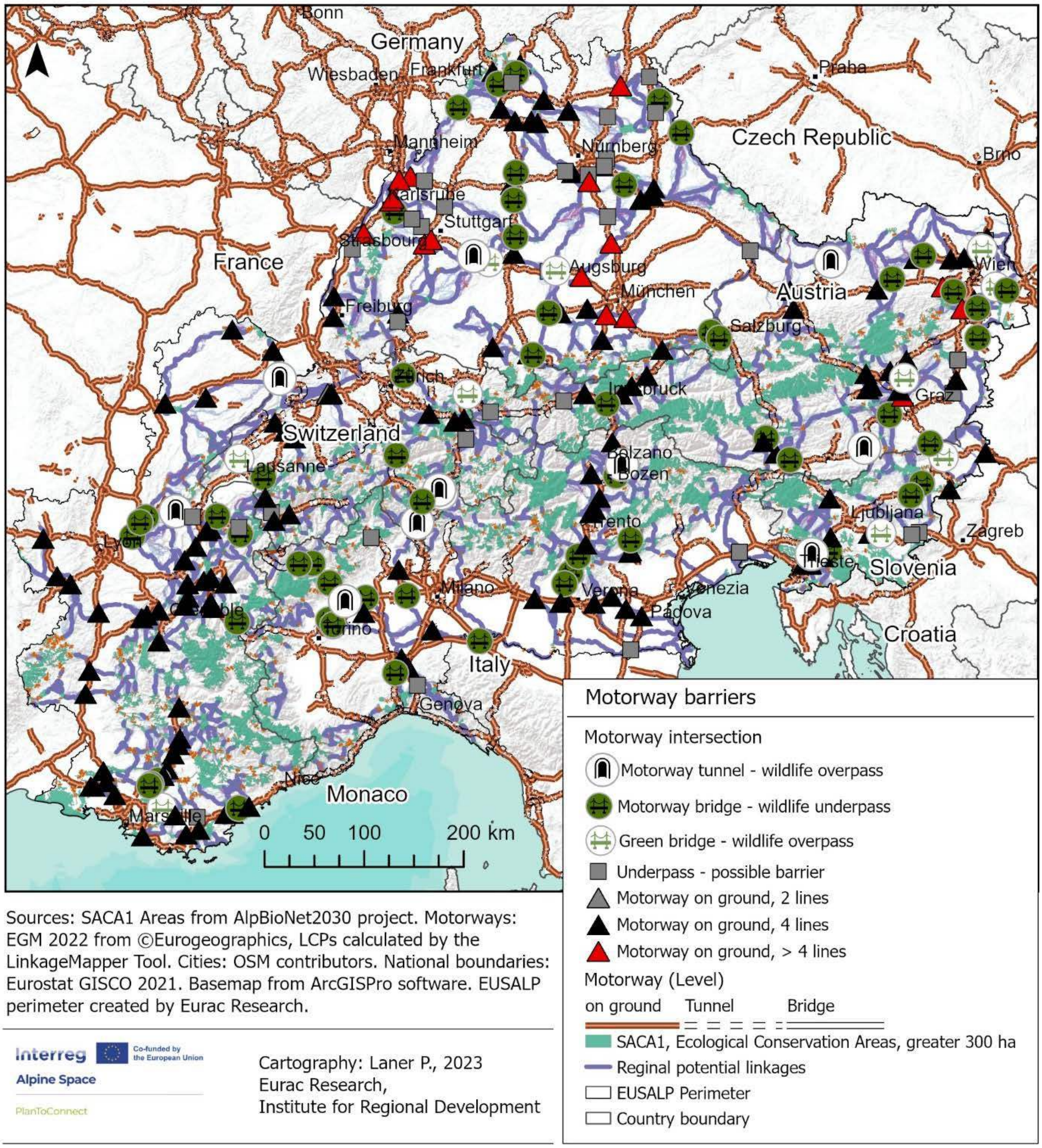
Picture 9: Green bridge in France between Pourcleux and Saint-Maximin-la-Sainte-Baume, in the north-east of Marseille

Underpasses:

The classification "underpasses" mostly mean the presence of smaller underpasses, often in case of small rivers or canals. Underpasses are often structured by artificial elements, therefore according to the IENE Wildlife and Traffic Handbook, they constitute "multiuse underpasses". This classification must be taken with caution, because these passings mostly seem very narrow and the functionality can't be verified with a great certainty from satellite images or Google Earth. A field visit and further studies on the functionality must be carried out.

The wildlife passing sign on the highway indicates a possible crossing point. The green line indicates the least- cost – path.

Picture 10: Underpass of a torrent flowing into the Inn River close to Heiming, Tirol, Austria



Sources: SACA1 Areas from AlpBioNet2030 project. Motorways: EGM 2022 from ©Eurogeographics, LCPs calculated by the LinkageMapper Tool. Cities: OSM contributors. National boundaries: Eurostat GISCO 2021. Basemap from ArcGISPro software. EUSALP perimeter created by Eurac Research.

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Figure 14. Overview of motorway intersections and their assumed barrier effects

4.3 Railway intersections

Intersections of the railway transport system with the LCPs and subgraph- distances from the macro-regional model were identified to analyse potential railway barriers. Railway data were taken from the EuroGlobalMap 2022 (EGM 2022), excluding tunnels and bridges. Only the location levels “on ground surface” and “unknown” were kept for representing real railway barriers. If tunnels or railway bridges are located in a distance of 2 kilometres, they were not counted as absolute barrier. 31 intersections with branch lines in Austria were excluded by filtering Railroad Category (RRC) and were not considered as real physical barriers because they have a very low structural barrier effect. No abandoned or disused railway track were used to investigate intersections, as the identified intersections according to the EGM (2022) dataset exist with railway lines in operation.

Barriers of high-speed train lines were analysed, assuming that they have a high barrier effect due to fencing, double tracks and the elevated speed. Upgraded high-speed railway lines (order of 200km/h) and dedicated high-speed railway lines (≥250km/h) were selected from the EGM (2022) dataset on railways, filtering these two types from the RSD Railroad Speed Class Data type. The result of an interpretation of the ArcGIS Pro satellite image shows that out of 31 intersections with high-speed train lines only 12 represent a real physical barrier. The others have an underpass or railway bridge nearby.

Out of 33 intersections with narrow-gauge railway lines, only 3 represent a real barrier. Railway intersections with river corridors in Italy were classified as “underpass” because they have no real barrier effect.

The remaining 353 railway intersections must be further investigated. This analysis was made with very general assumptions and just indicates first results. More specific analysis, like filed visits e.g., are needed to verify if real physical railway barriers exist in those cases.

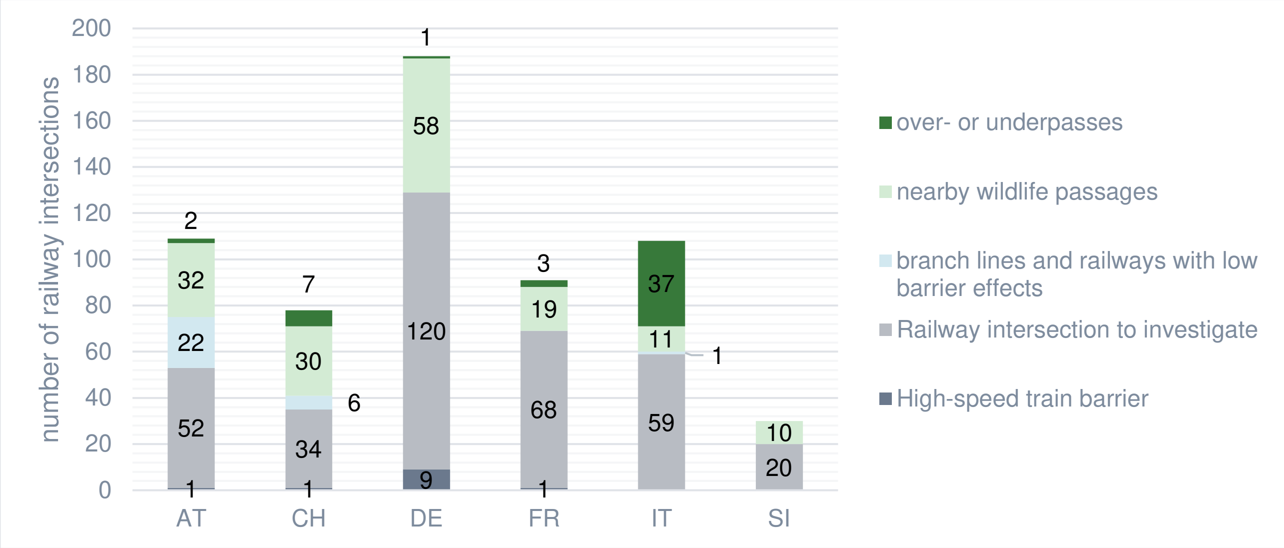
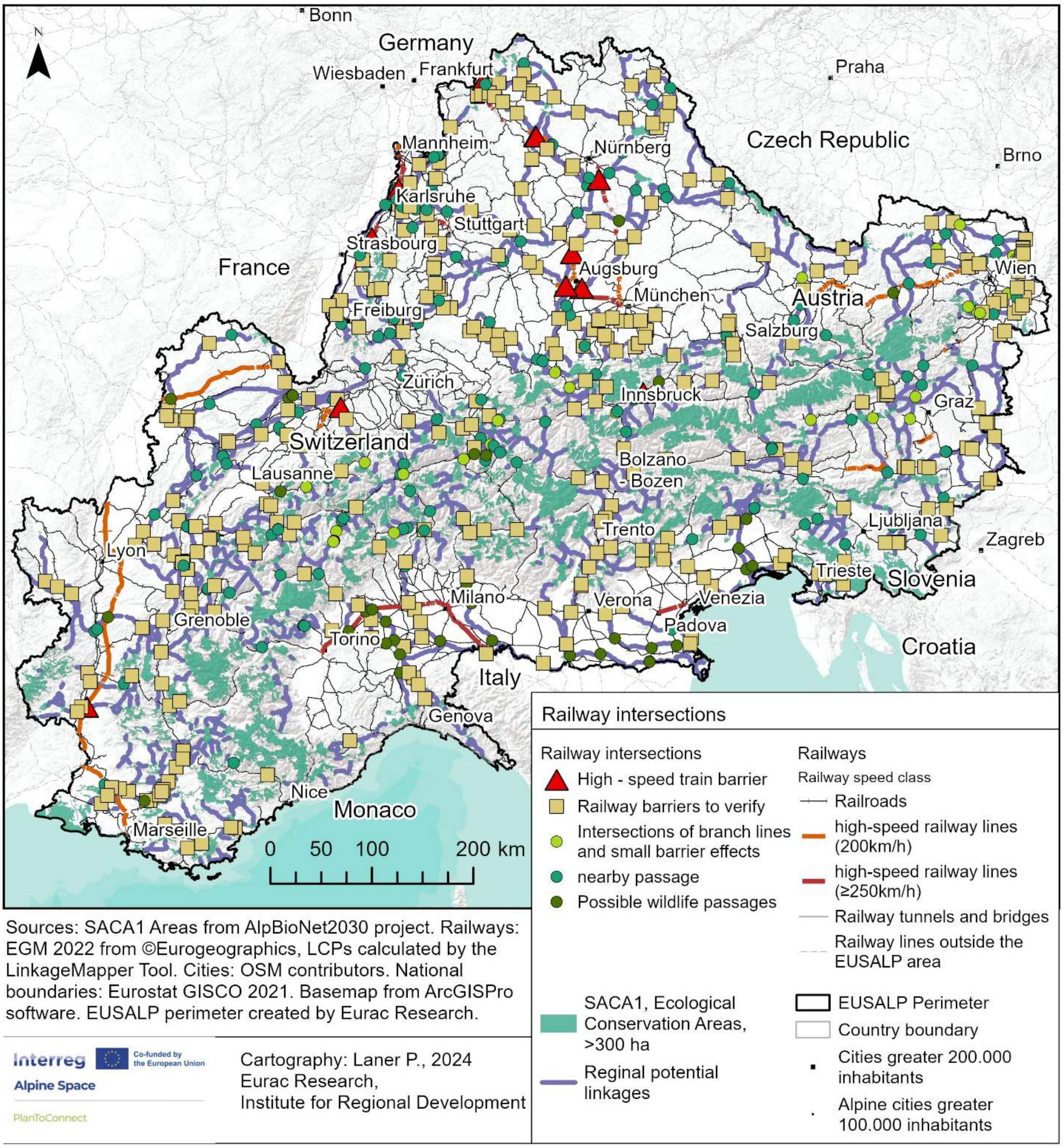


Figure 15: Railway intersections with potential linkages by country



Sources: SACA1 Areas from AlpBioNet2030 project. Railways: EGM 2022 from ©Eurogeographics, LCPs calculated by the LinkageMapper Tool. Cities: OSM contributors. National boundaries: Eurostat GISCO 2021. Basemap from ArcGISPro software. EUSALP perimeter created by Eurac Research.

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Figure 16: Railway line intersections with potential linkages and assumed barrier effects

4.4 Solar panel fields

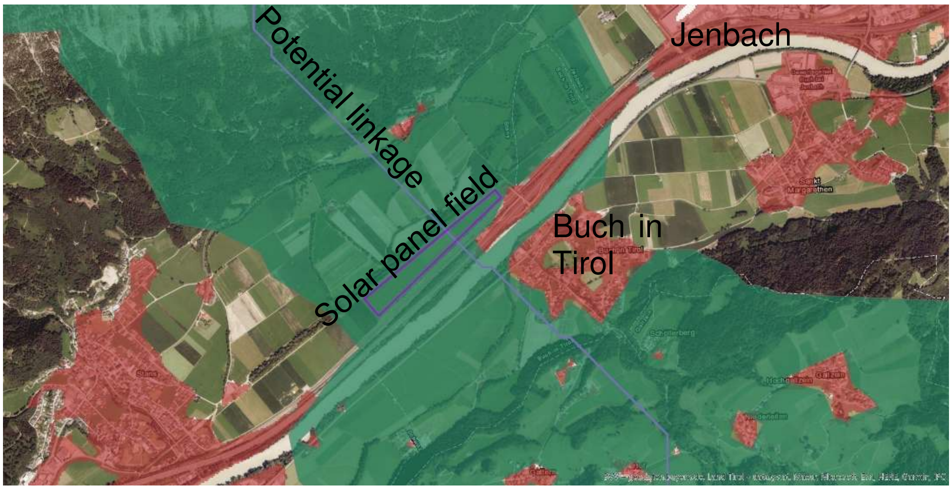
Solar panel fields contribute to the cumulative anthropogenic impact and land fragmentation. Therefore, major solar panel fields were extracted by open street map data and intersections with potential regional linkages were analysed.

Areas of solar panel installations were downloaded from OpenStreetMap by the Overpass Turbo website (https://overpass-turbo.eu/) using the query “nwr["generator:source"="solar"]” on single map tiles and the query nwr["plant:source"="solar"] on the whole EUSALP extent. Polygons and polylines were extracted from the downloaded GeoJSON files and merged to a single dataset. This was clipped to the EUSALP perimeter. For cleaning the solar panel dataset, identical geometries resulted from overlapping map tiles were deleted to avoid duplicates. Areas with attributes indicating that the panels are located on roofs were excluded from the dataset, because the objective of the barrier analysis is to focus on solar fileds on ground surface. To simplify the analysis, only solar panel fields outside the built-up areas from the Esri Sentinel-2 10m Land Use/Land Cover dataset 2022 were selected because settlement barriers were already analysed in a former step. Those which fall completely within a built-up area were not considered (ArcGISPro command “select by location”, relationship “completely within”). By a visual interpretation it was revealed that solar panel installations up to approximately 1.000 m² which intersect built-up areas were mostly found on roof tops or they belong to the buildings and settlements nearby. Thus, they were not considered in the barrier analysis. Finally, only solar panel installations inside the corridor width designed by linkage mapper were considered.

The results are showing that in total 194 potential regional linkages are affected by solar panel fields bigger than 1.000 m². This corresponds to each fifth linkage. Only 20 of them are affected in a serious way:

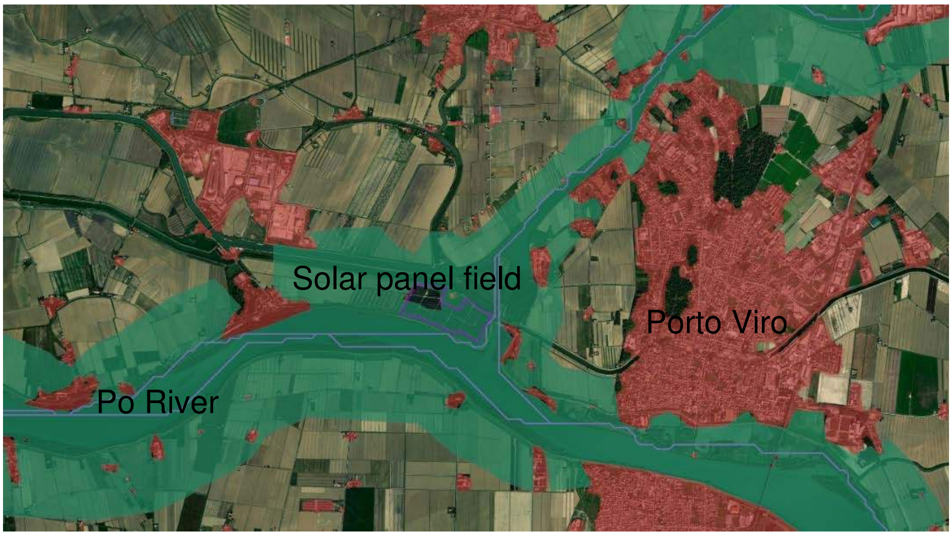
1. For three corridors, a solar panel field represents already a structural barrier.
2. Due to solar panel fields, 17 situations of structural bottlenecks were identified:
   - 3 linkages have a bottleneck of less than 300 m.
   - 7 linkages have a bottleneck of 300 – 650 m.
   - 5 linkages have a bottleneck of 651 – 1.000 m.
   - 2 linkages have a bottleneck of 1.000 – 1.500 m.

However, the relatively new trend of upcoming solar panel fields is a threat for potential linkages in the future.



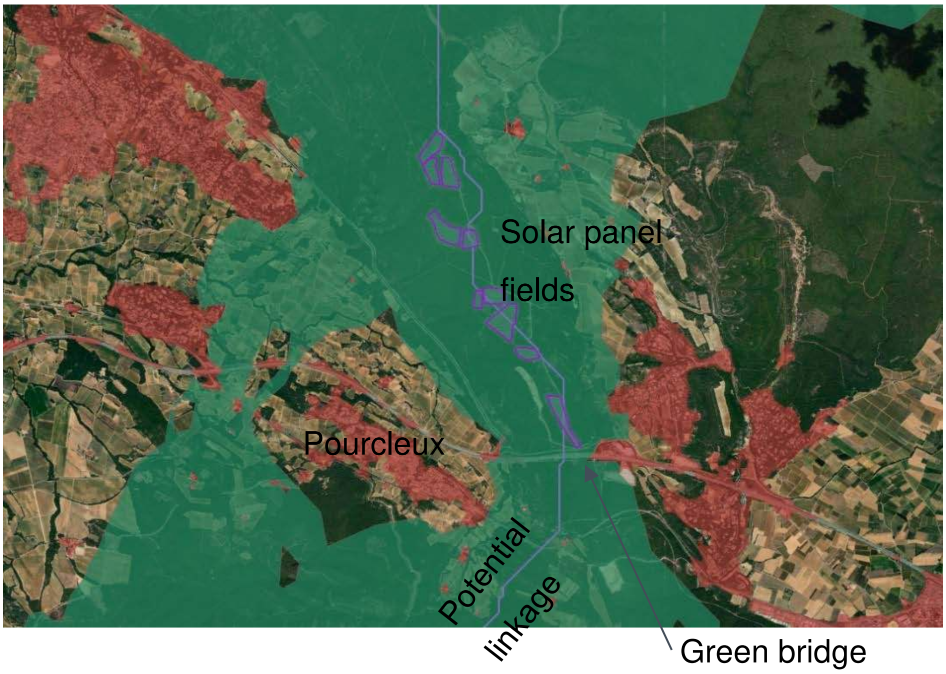
Picture 11: "*Solarpark Stans*", Tirol, Austria

A solar park in Tirol (AT) between Stans and Jenbach, put into operation in February 2023 (MeinBezik.at, 2023), represents an additional barrier in the valley bottom of the Inn Valley. This location is one of the last six potential connections from the southern to the northern mountain slope in the Inn valley between Imst and Kufstein and it is already compromised by the barrier effects of the motorway, train line, and rectified river.



Picture 12: Solar panel field “Loreo”, Italy

The solar panel field Loreo, next to the Po River near Porto Viro, in Veneto (IT), which was finalised in 2023 (ilgazzettino.it, 2023), represents a structural barrier for a potential green corridor along the Po River and its distributary channels. The solar panel field is fenced and in combination with the settlement structures and intensive agriculture it interrupts green infrastructure connectivity.



Picture 13: Solar panel fields on a potential linkage in the north of Pourcleux, France

In the north of Pourcleux, in the region of Provence-Alpes-Côte d'Azur, France, a series of solar panel fields are creating a structural bottleneck of 500 to 650 m for a forest connection. The solar panel fields are surrounded by forests and located behind a green bridge, overpassing the A8 motorway, which confirms the importance and the functionality of the corridor.

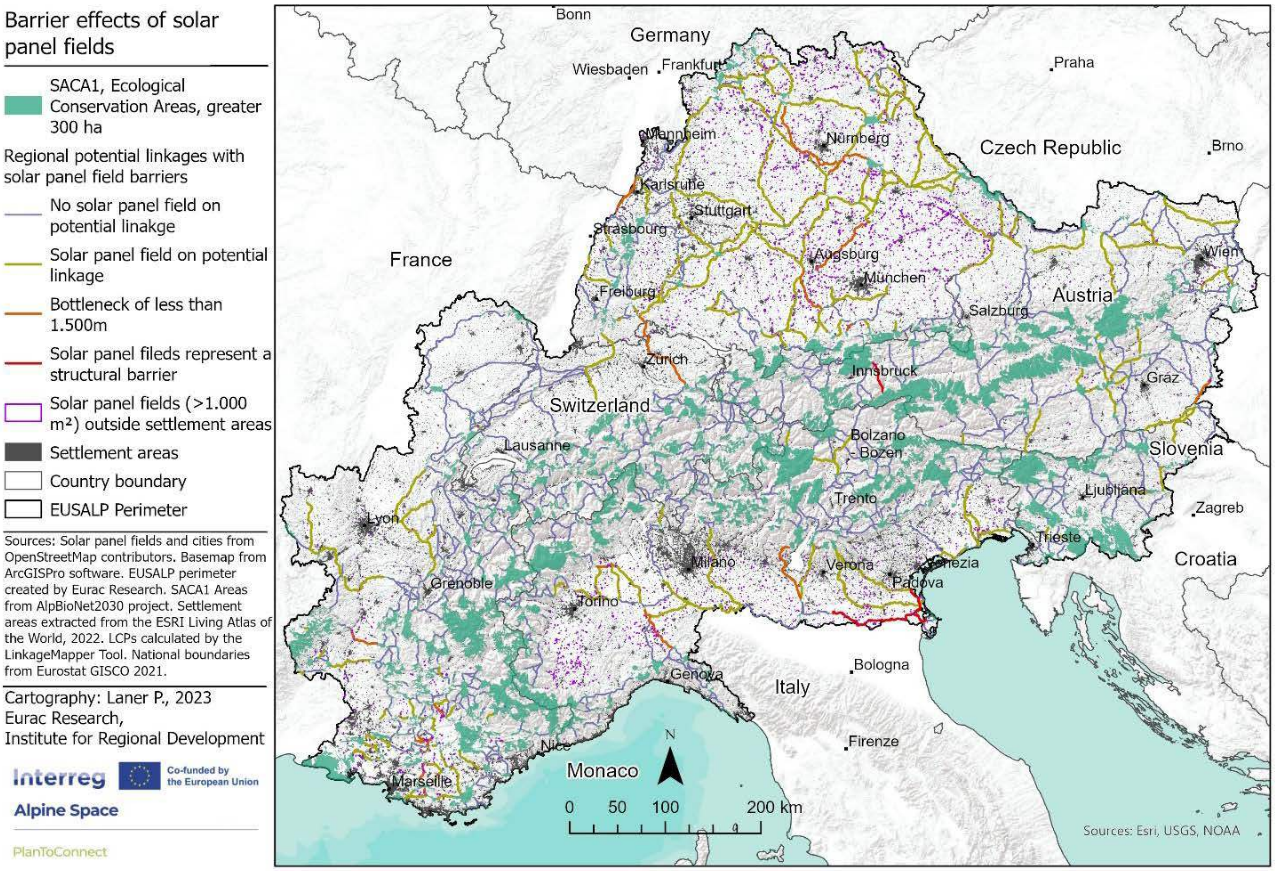


Figure 17: Barrier effects of solar panel fields on regional potential ecological linkages

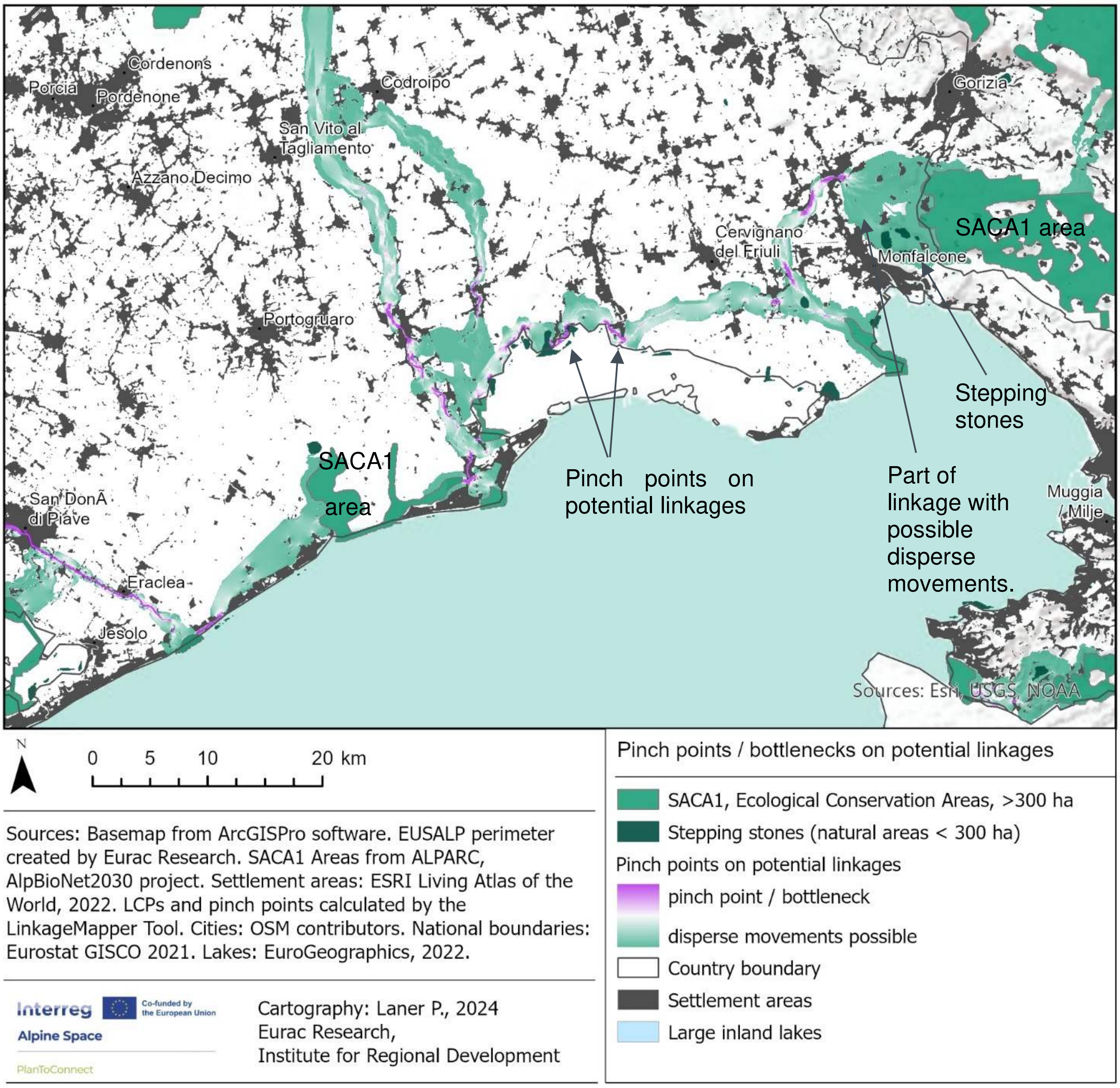
4.5 Bottlenecks/ pinch points

The LinkageMapper toolbox provides the Pinchpoint Mapper tool, which “can be used to identify and prioritize important areas for connectivity conservation” (McRae, 2012). This tool complements the least-cost path results with electric circuit analysis *by “identifying important alternative pathways and “pinch points,” where loss of a small area could disproportionately compromise connectivity”* (ibid.).

The highlighted pinch points are showing constraints of current flow on the best corridor and shows “*both, the most efficient movement pathways and critical pinch points within them” (ibid.).* For spatial and landscape planning it is useful to focus on the pinch points, (i.e. bottlenecks on the least-cost-paths) and prioritize them over areas that are more open and therefore less crucial for connectivity conservation.

The following examples are showing some crucial pinch points / bottlenecks that should be preserved by spatial and landscape planning instruments in some of the PlanToConnect pilot sites.

The detailed data are visible on the Web GIS platforms.



Sources: Basemap from ArcGISPro software. EUSALP perimeter created by Eurac Research. SACA1 Areas from ALPARC, AlpBioNet2030 project. Settlement areas: ESRI Living Atlas of the World, 2022. LCPs and pinch points calculated by the LinkageMapper Tool. Cities: OSM contributors. National boundaries: Eurostat GISCO 2021. Lakes: EuroGeographics, 2022.

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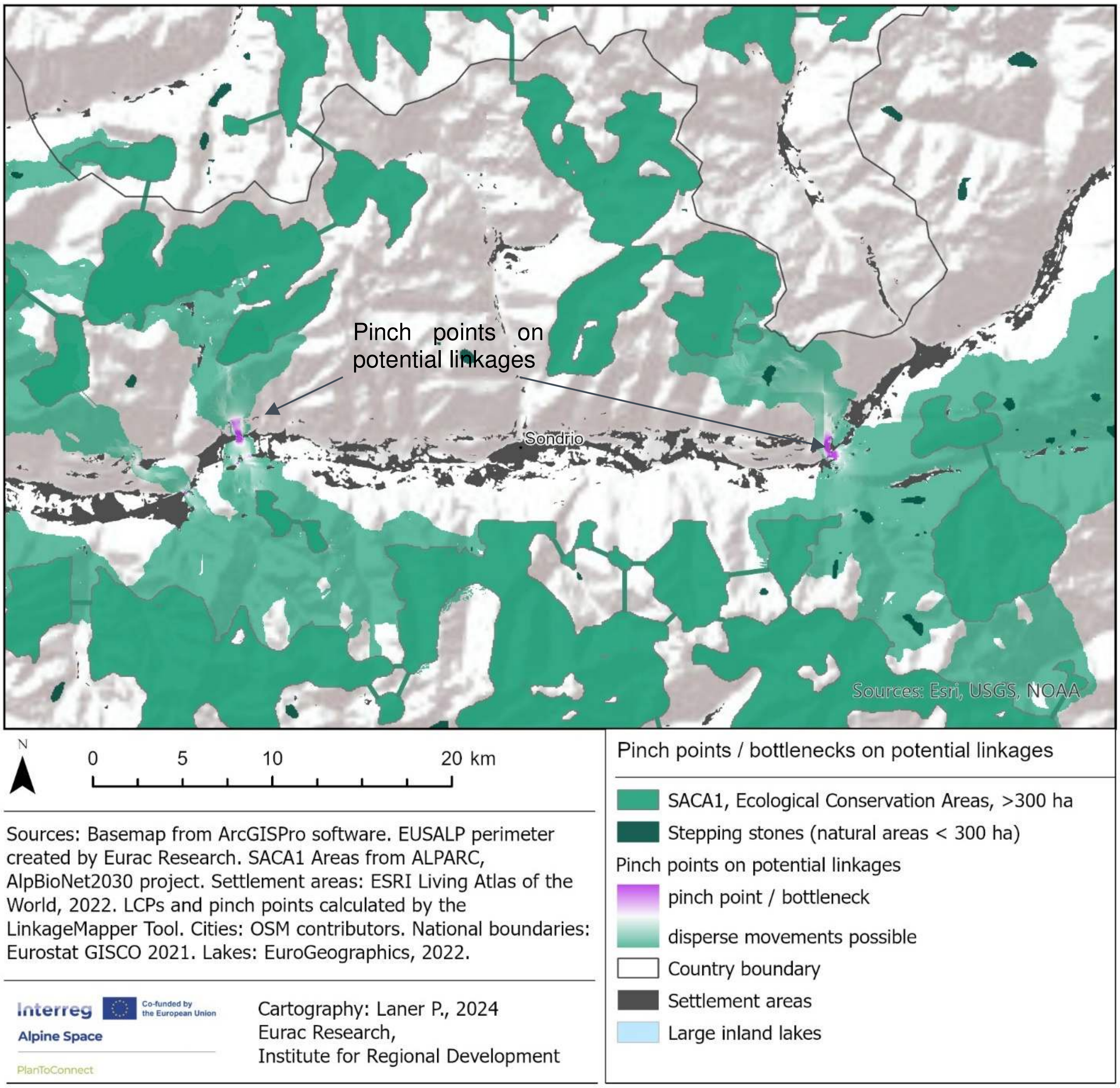
Figure 18: Bottlenecks in the pilot site of Veneto Region (IT)



Sources: Basemap from ArcGISPro software. EUSALP perimeter created by Eurac Research. SACA1 Areas from ALPARC, AlpBioNet2030 project. Settlement areas: ESRI Living Atlas of the World, 2022. LCPs and pinch points calculated by the LinkageMapper Tool. Cities: OSM contributors. National boundaries: Eurostat GISCO 2021. Lakes: EuroGeographics, 2022.

Cartography: Laner P., 2024
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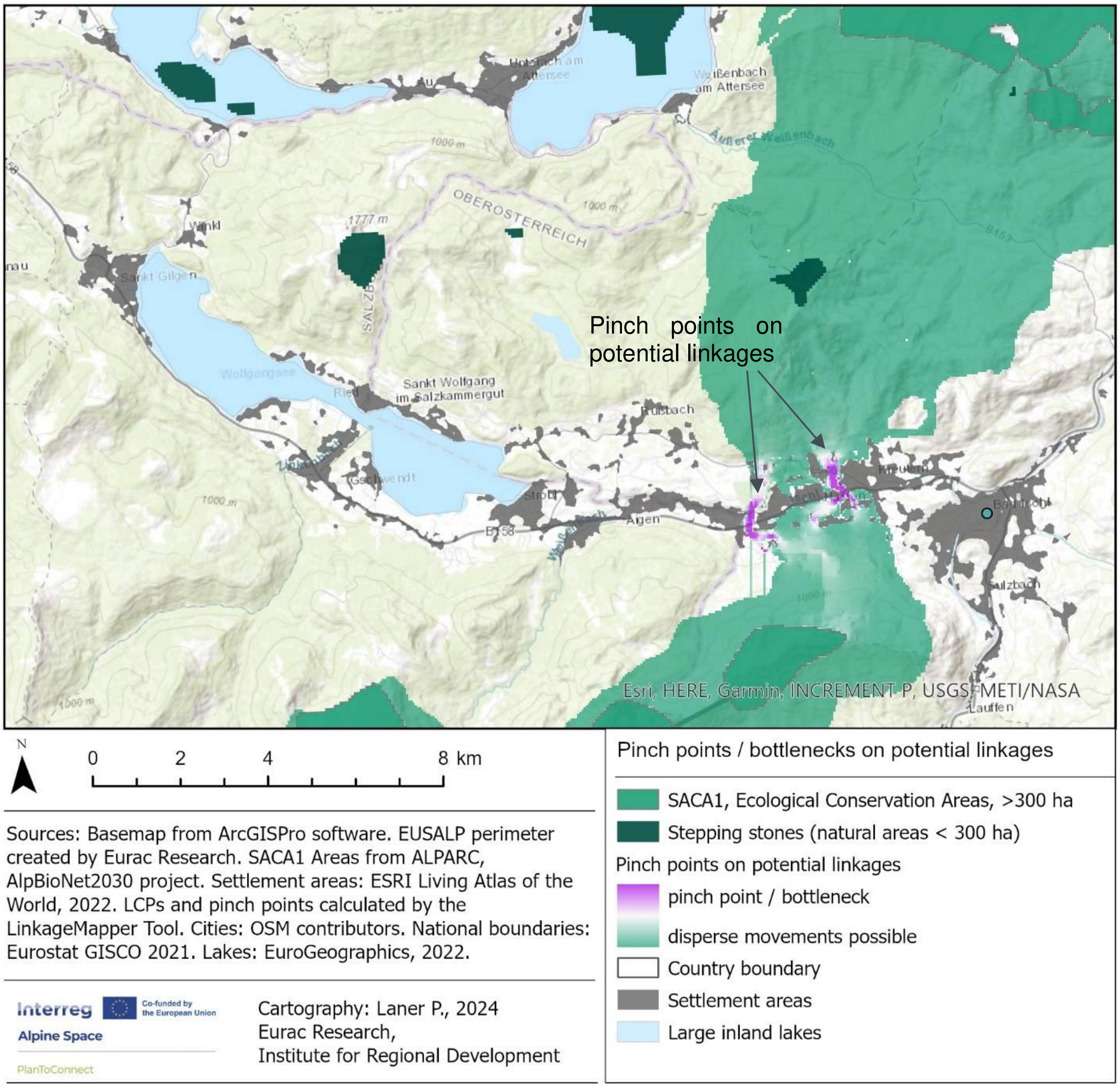
Institute for Regional Development

Figure 19: Bottlenecks in the pilot site of Sondrio (IT)



Sources: Basemap from ArcGISPro software. EUSALP perimeter created by Eurac Research. SACA1 Areas from ALPARC, AlpBioNet2030 project. Settlement areas: ESRI Living Atlas of the World, 2022. LCPs and pinch points calculated by the LinkageMapper Tool. Cities: OSM contributors. National boundaries: Eurostat GISCO 2021. Lakes: EuroGeographics, 2022.

Cartography: Laner P., 2024
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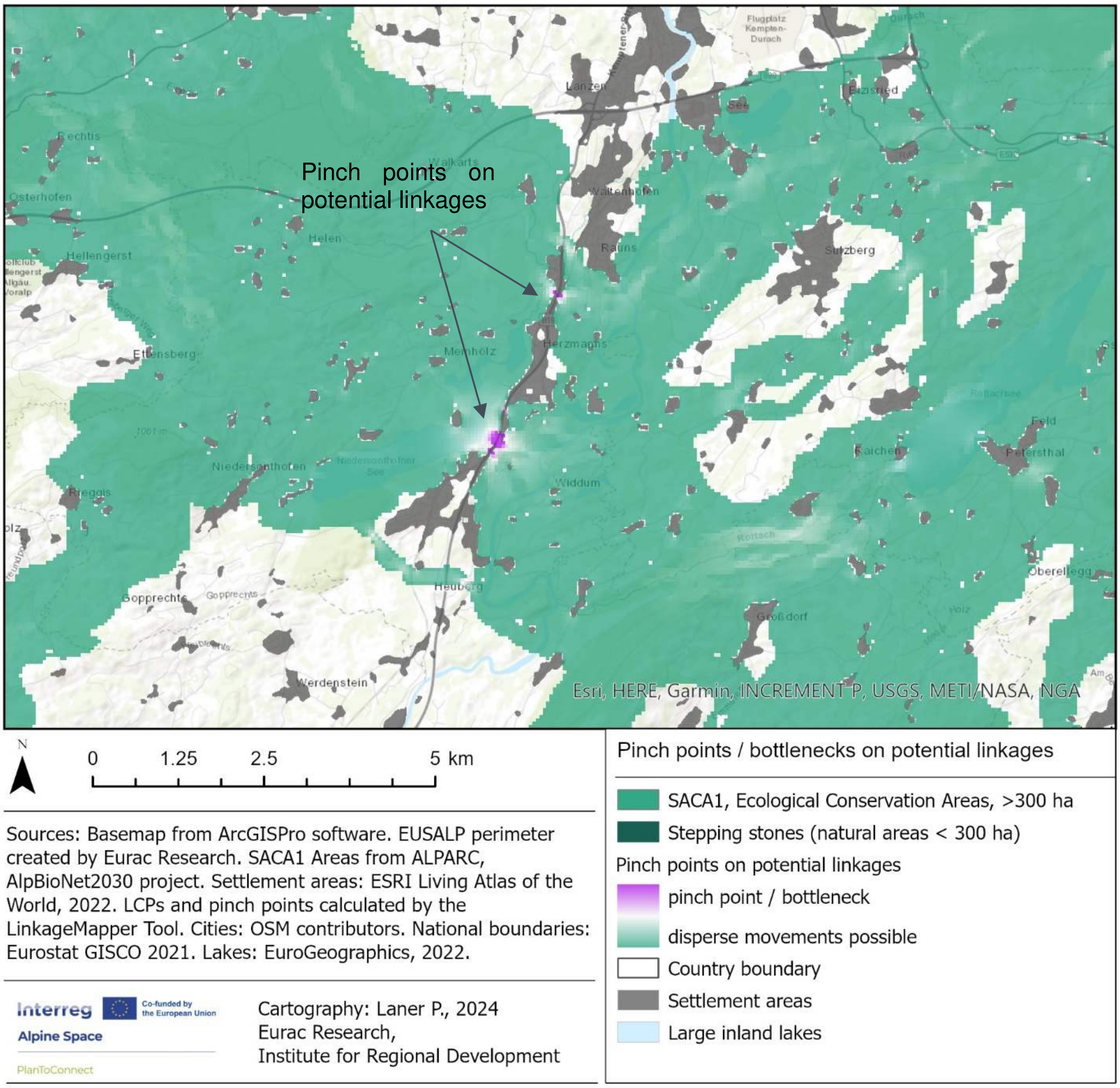
Figure 20: Bottlenecks in the pilot site of Salzburg (AT)



Sources: Basemap from ArcGISPro software. EUSALP perimeter created by Eurac Research. SACA1 Areas from ALPARC, AlpBioNet2030 project. Settlement areas: ESRI Living Atlas of the World, 2022. LCPs and pinch points calculated by the LinkageMapper Tool. Cities: OSM contributors. National boundaries: Eurostat GISCO 2021. Lakes: EuroGeographics, 2022.

Cartography: Laner P., 2024
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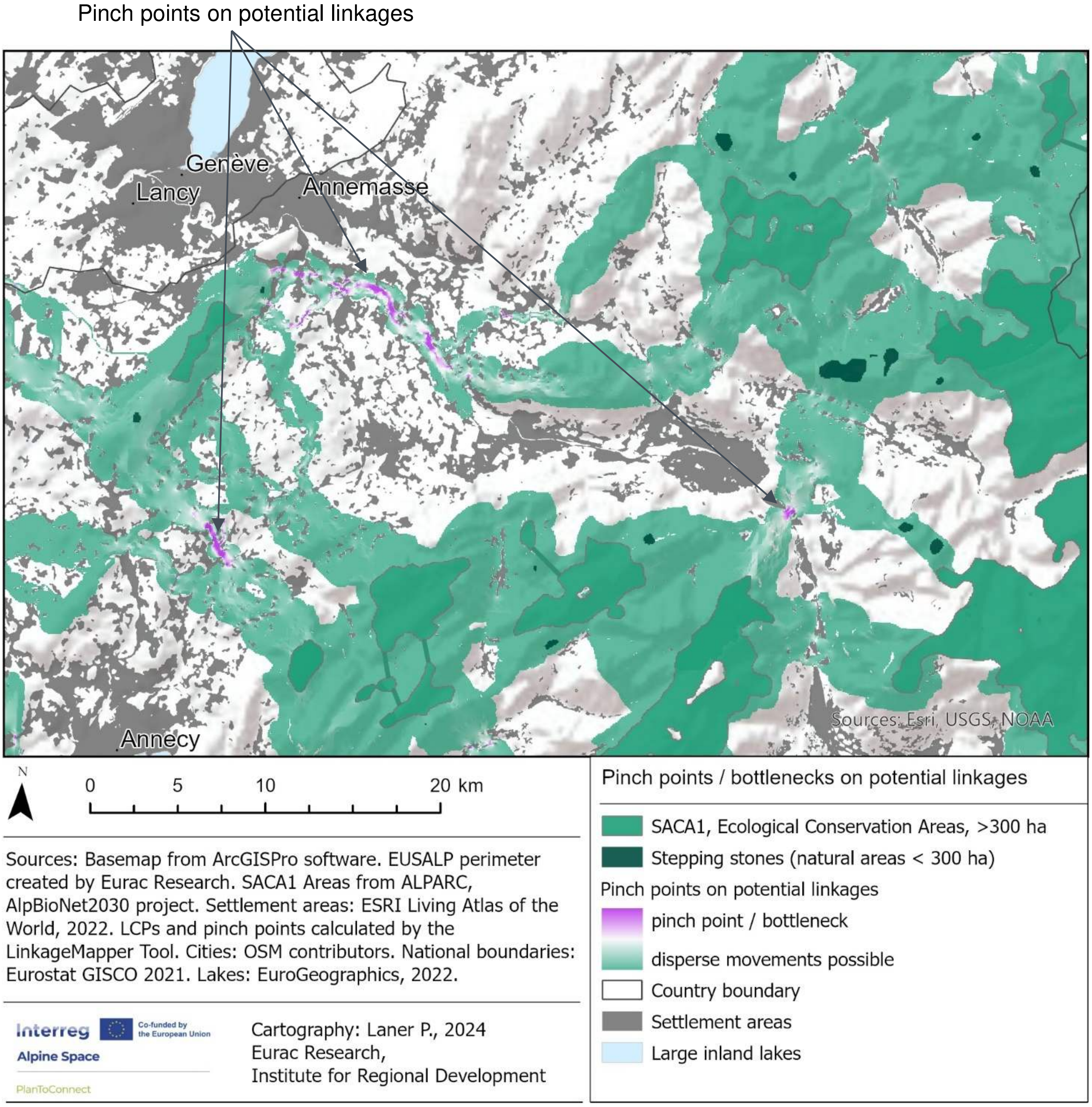
Figure 21: Bottlenecks in the pilot site near regional park Nagelfluhkette (DE)



Sources: Basemap from ArcGISPro software. EUSALP perimeter created by Eurac Research. SACA1 Areas from ALPARC, AlpBioNet2030 project. Settlement areas: ESRI Living Atlas of the World, 2022. LCPs and pinch points calculated by the LinkageMapper Tool. Cities: OSM contributors. National boundaries: Eurostat GISCO 2021. Lakes: EuroGeographics, 2022.

Cartography: Laner P., 2024
Eurac Research,
Institute for Regional Development

Figure 22: Bottlenecks in the pilot site of Upper Savoy (FR)

5 Prioritization of regional potential linkages

Following the approach of Beier et al. (2013), the prioritization tries to combine two different dimensions. One dimension could be the biological value of the linkages. However, experiences from the Alpine Parks 2030 project show that it is difficult to find sound datasets, which can depict biological values for the whole macro-region EUSALP.

"*What is missing very often in the analysis is the ecological or biological value of an area. We have been confronted to this problem too in our work Alpine Parks 2030 and worked for this reason with the KBA's and as well with NATURA2000/Emerald as this both "labels" are an expression of a confirmed "ecological value" of an area. We do not have enough data on biodiversity for the Alps. Data is local and often not comparable.*" (Plassmann & Coronado-Cortes 2023) Therefore, it was tried to avoid using functional criteria to define a biological value and stick to the structural approach.

The first dimension of the prioritisation follows the objectives of keeping the network together, and, according to Beier et al. (2013), to identify those linkages, which are restorable. Linkages were classified by their contribution to the interconnectedness of SACA1 areas, to create a coherent alpine -wide network, and according to their restorability.

The second dimension of the prioritisation follows the logic of threats to which a potential linkage is exposed to. It is more important to focus on certain linkages because they are at greater risk of being irreversibly lost (ibid.).

Potential linkages which are threatened by urbanisation processes, including industrial and residential settlement areas, were considered. These are the most important land uses, on which spatial planning has a strong influence.

The following criteria and indicators were selected:

1. Structural importance to keep the network together (structural - biological value).
    a. The restorable habitat quality:
    The restorable habitat quality can be indicated by the cumulative resistance, expressed by the cost-weighted distance of a linkage, which is a result of the calculation by the Linkage Mapper tool. Within the cost weighted distance (CWD), characteristics like the length of a linkage, the amount of motorway barriers to overcome, or passages of intensively used agricultural areas to overcome are included in a numeric fictious value without unit (see Figure 25, Figure 26, and Figure 27, in Annex 3). The minimum spanning tree calculated in section 3.5.1 is based on the cost-weighted-distance and represents the best path to connect a SACA1 area with its nearest neighbours and other sub-networks, called "constellations". Therefore, the contribution of a linkage to the minimum spanning tree was selected as indicator.

b. Centrality:

The highest category type of the current flow centrality was selected as indicator. It mainly represents linkages, which are important for the connectivity of the inner alpine space, see section 3.5.2.

c. Importance for counteracting the island effect:
The indicator is the contribution to connectivity areas from ALPBIONET2030, as shown in section 3.5.3.

2. Risk of getting irreversibly lost.

d. Urbanisation threat. The existence of one or several bottlenecks due to urbanization was selected as an indicator.

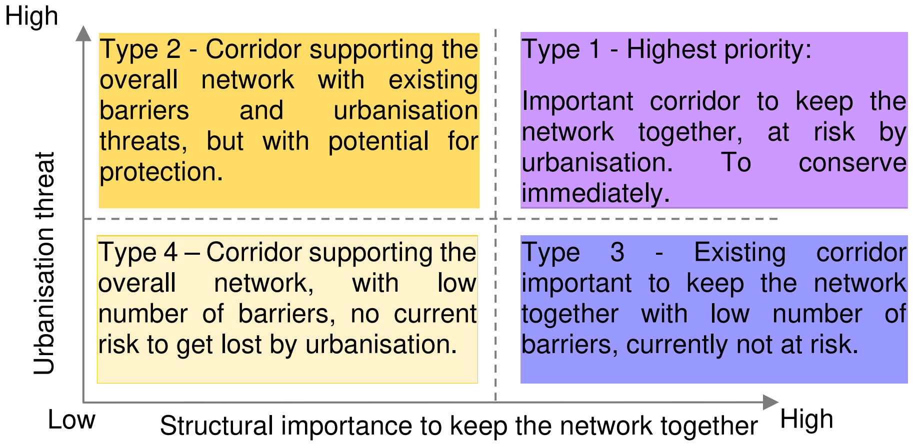


Figure 23: Scheme for prioritizing ecological corridors

The resulting map shows four types of linkage priorities (see Figure 22):

- Type 1 linkages are those, which should be restored and protected from urbanisation very soon. These 170 linkages are very important to keep the network together, but are highly at risk by urbanisation processes, having at least one bottleneck of 300m on their path. The linkages are mostly located in pre-alpine areas, connecting the inner with the outer Alpine Space. Although 106 out of 170 are contributing to the minimum spanning tree, they can have relatively high cost-weighted distances (see Figure 21). Each third linkage of this type has a motorway barrier on the path.
- Type 2 linkages often are located in the pre-alpine flatlands and are threatened by urbanisation. These 139 linkages have a similar characteristic to Type 1 linkages,

however they are not fulfilling one of the criteria of the structural importance to keep the network together. Often, they are difficult to restore, have only a medium to low centrality or are not connecting the most important SACA1 areas between the inner and outer Alpine Space. 50 of them have at least one motorway barrier on their path.

- Type 3 linkages are mainly situated in the inner Alpine Space. Almost half of all linkages (470 out of 953) are falling in this category. Approximately half of them (249 linkages) have a high centrality and 359 of them are part of the minimum spanning tree, so they are important for keeping the inner network together. They are less threatened by settlement development, and a potential restorability should be given. 152 of them are passing through intensive agriculture, but only 31 of them have motorway barriers on their path.
- Type 4 linkages are those which should have the least priority to focus on. These 174 linkages are mostly located in the inner Alpine Space but are less important for keeping the overall network together and are less threatened by urbanisation at the moment. Only 26 of them have a motorway barrier on their path.

The classification shows a difference between priority types and cost-weighted distances, which is composed by length and barriers on the path, and thus a sort of indicator for restorability. Type 1 and type 2 linkages, which are mostly located in the outer Alpine Space tend to include those with higher cost-weighted distances. Type 3 and type 4 linkages, which are mostly located in the inner Alpine Space do not achieve such high values as the others.

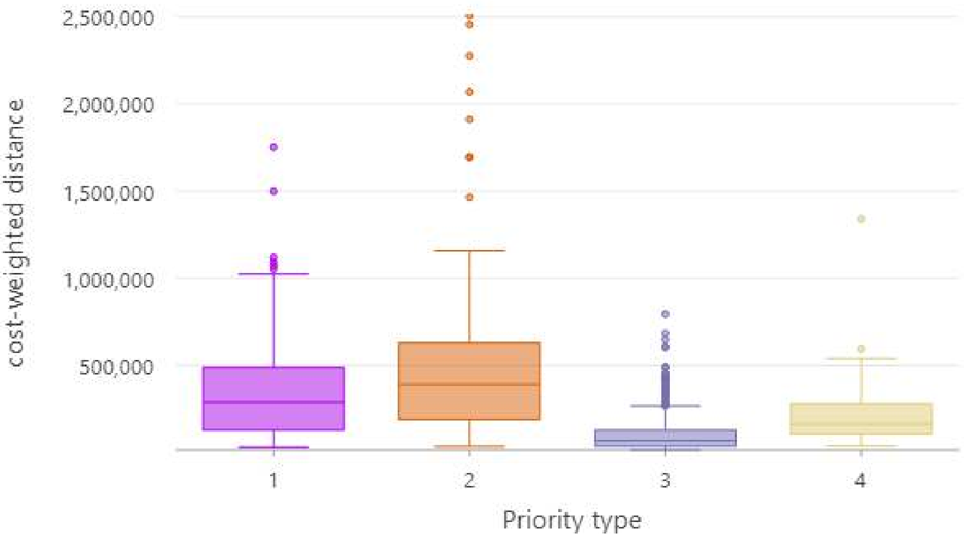
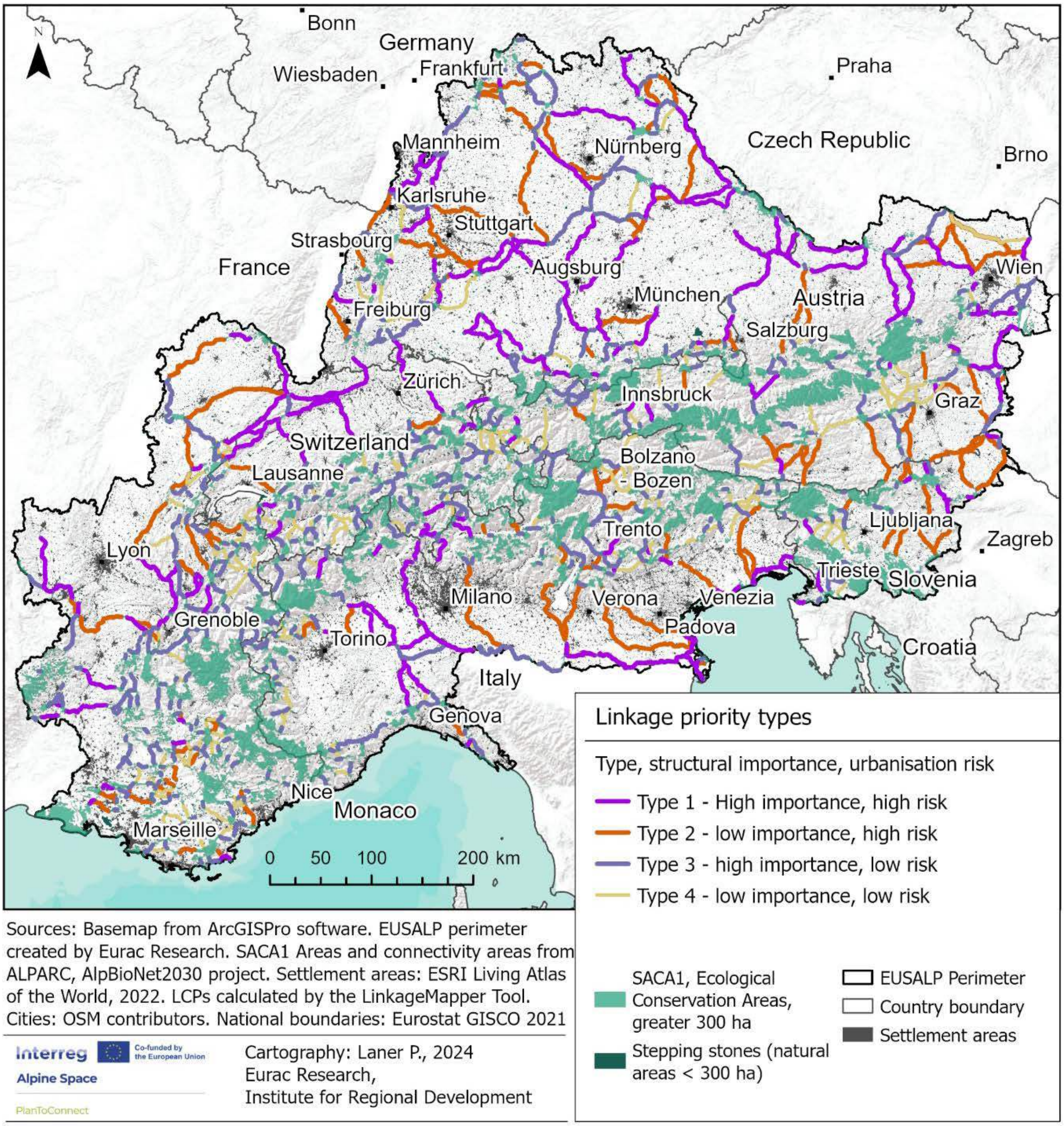


Figure 24: Distribution of cost -weighted distances by priority type



Sources: Basemap from ArcGISPro software. EUSALP perimeter created by Eurac Research. SACA1 Areas and connectivity areas from ALPARC, AlpBioNet2030 project. Settlement areas: ESRI Living Atlas of the World, 2022. LCPs calculated by the LinkageMapper Tool. Cities: OSM contributors. National boundaries: Eurostat GISCO 2021

Cartography: Laner P., 2024
Eurac Research,
Institute for Regional Development

Figure 25: Linkage priority types for spatial planning

6 Catalogue of GBI typologies

Typology of GBI infrastructure and GBI elements

In the “Green infrastructure implementation and efficiency report” (Bennett et al. 2011), the terms “GBI typology” and “GBI elements” are used synonymously.

Despite some scientific articles referring to the term “GBI elements”, there was no dedicated scientific definition found so far. In recent scientific literature, the term “GBI elements” is used to describe areal, linear or punctual parts of the landscape matrix. Staccione et al. (2022) describes core areas and corridors as green network elements. Concepción et al. 2020 describes semi-natural GBI elements in agricultural landscapes. These can be e.g., field margins, hedgerows, fallow land, pastures, woodlands. A table of habitat indicators linked to distinct GBI elements and options supported by greening of agriculture was elaborated by Concepción et al. (2020) in an international study.

“According to sources such as the European Commission (2013), Beery et al. (2017), and Ghofrani et al. (2017), GBI includes natural, semi-natural, and artificially created multi-functional elements. Although considerable attention is paid to GBI, there is no uniform typology for it (Young et al., 2014). GBI can be categorised according to function, position, and scale (Ghofrani et al., 2017).

The following main typologies of green infrastructure elements can be distinguished at various scales (Bennett et al. 2011 in Campagna et al. 2020):

1. core areas of high biodiversity value;
2. restoration zones such as reforestation areas;
3. ecosystem service zones oriented to provide a range of ecosystem service benefits;
4. green urban and peri-urban areas such as urban parks and green roofs;
5. natural connectivity features to assist species movement.
6. artificial connectivity features

Table 10:Typology of green infrastructure elements by Benett et al. (2011)

Green Infrastructure element	Includes:
Core areas	Areas of high biodiversity importance, including large areas of healthy and functioning ecosystems with minimal intervention required, and smaller areas that require management; such as Natura 2000 areas and other protected areas (eg IUCN categories I, II and IV).
Restoration zones	Reforestation zones, new areas of habitat for specific species or restored ecosystems for service provision.
Sustainable use/Ecosystem Service Zones	Areas that are managed sustainably for economic purposes, whilst maintaining healthy ecosystems and proving a range of ecosystem service benefits (eg multi-use forests and High Nature Value farming systems). Such areas help maintain the permeability of the landscape (ie enable species to exist in the wider landscape and move between core areas)
Green urban and peri-urban areas	Parks, gardens, grassy verges, green walls, green roofs.
Natural connectivity features	Ecological corridors (hedgerows, wildlife strips, stone walls) stepping stones (ie patches of habitat that enable species to move between core areas), riparian river vegetation, etc.
Artificial connectivity features	Features that are designed specifically to assist species movement, such as green bridges (ie bridges that are covered by an appropriate habitat to encourage the movement of animals across them), tunnels and fish passes.

The PlanToConnect project is mainly focusing on core areas of high biodiversity value, restoration zones, sustainable use zones, and natural and artificial connectivity features to assist species movement.

Considering scientific literature, “GBI elements” can be defined as parts of the GBI network in the landscape matrix, with a natural or semi-natural characteristic. Therefore, the PlanToConnect project considers GBI elements on regional or macro-regional level as homogenous areas of land cover classifications within natural and semi-natural connectivity features (e.g., ecological corridors or other high permeable parts of the landscape).

To provide a catalogue of GBI typologies that are important for ecological connectivity in the Alps, we filtered detailed land use / land cover classifications present on identified potential regional ecological linkages.
For this, the detailed land use/ land cover classifications of 5x5m by Marsoner et al. (2023) was used and categorized by GBI typologies according to Benett et al. (2011).

GBI Type 1 - Core areas:
From a structural point of view, SACA1 areas can be defined as core areas.

GBI Type 2 - Possible restoration zones:
Agricultural practices on potential ecological linkages can lead to conflicting uses and should be possibly restored with connecting elements (e.g. woody features).

Table 11: Possible restoration zones (GBI Type 2)

Land use / land cover class	Area [km²]	Percent
21219 - Other cereals	0.07	0.00%
21223 - Other root crops	0.51	0.00%
21215 - Oats	1.89	0.00%
21218 - Triticale	2.20	0.00%
21230 - Other non-permanent industrial crops	3.45	0.00%
21217 - Rice	4.80	0.00%
21212 - Durum wheat	13.78	0.01%
21233 - Soya	30.01	0.03%
21290 - Bare arable land	45.42	0.05%
21214 - Rye	53.66	0.05%
21221 - Potatoes	56.70	0.06%
22000 - Permanent crops	63.52	0.06%
21240 - Dry pulses	94.48	0.09%
21250 - Fodder crops (cereals and leguminous)	120.32	0.12%
21231 - Sunflower	177.35	0.18%
21222 - Sugar beet	235.46	0.23%
22200 - Orchard	294.33	0.29%
22100 - Vinyard	430.71	0.43%
21232 - Rape and turnip rape	505.31	0.50%
12221 - Roads tertiary and others	509.08	0.51%
21213 - Barley	1,044.96	1.04%
21000 - Cultivated areas - Arable land - Annual crops	3,395.02	3.37%
21211 - Common wheat	3,447.37	3.43%
21216 - Maize	3,740.24	3.72%
23100 - Managed grassland - Pastures	7,212.29	7.17%
Sum	**21,483**	**21.35%**

GBI Type 3 - Sustainable use zones:
A detailed analysis of sustainable use zones will be part of activity 1.2 on conflicting and compatible uses for ecological connectivity, possibly by the evaluation of high nature value agricultural areas. Seminatural grassland and managed grassland areas are candidates for such areas.

Table 12: Possible sustainable use zones (GBI type 3)

Land use / land cover class	Area [km²]	Percent
23200 - Seminatural grassland - Meadows	7,116.96	7.07%
Sum	**7,116.96**	**7.07%**

GBI Type 4 - Green urban and peri-urban areas:
Urban GBI elements are playing a minor role in in an alps-wide model.

Table 13: Green urban and periurban areas (GBI type 4)

Land use / land cover class	Area [km²]	Percent
31450 - Tree cover in urban context	24.37	0.02%
14100 - Green urban areas	25.90	0.03%
11400 - Open settlement area	34.55	0.03%
11200 - Low density settlement area	37.08	0.04%
Sum	**122**	**0.12%**

GBI Type 5 - Natural connectivity features:
Natural connectivity features on potential ecological linkages constitute the main part of potential ecological linkages with almost 70%.
It is questionable if permanent snow-covered surface can be classified as natural connectivity features because such areas can constitute a barrier depending on the species. Therefore, it was not aggregated to the list.

Table 14: Natural connectivity features (GBI type 5)

Land use / land cover class	Area [km²]	Percent
52100 - Lagoons and Estuaries	0.01	0.00%
42200 - Intertidal flats	0.03	0.00%
41200 - Peatbogs	0.66	0.00%
42100 - Coastal salt marshes	1.73	0.00%
51200 - Riverbed > 10m width	9.11	0.01%
32300 - Sclerophyllous vegetation	15.07	0.01%
32200 - Moors and heathland - other scrubland	28.37	0.03%
31600 - Patchy woody features	29.13	0.03%
33300 - Sparsely vegetated land	112.72	0.11%
33100 - Beaches, dunes, sands	120.74	0.12%
51100 - Rivernetwork	129.41	0.13%
31200 - Coniferous tree cover	144.77	0.14%
41000 - Wetland (permanent wet areas) - inland marshes	209.92	0.21%
31100 - Broadleaf tree cover	238.08	0.24%
31610 - Additional woody features	274.11	0.27%
33200 - Bare rocks and rock debris	436.37	0.43%
31400 - Tree cover in agricultural context	568.97	0.57%
31500 - Green linear elements - linear woody features	643.93	0.64%
51000 - Water bodies	728.21	0.72%
32100 - Alpine and sub-alpine natural grassland	1,368.27	1.36%
31202 - Coniferous tree cover 30-60%	2,516.64	2.50%
31300 - Mixed tree cover	2,764.57	2.75%
32000 - Scrub and shrubland	3,486.08	3.46%
31102 - Broadleaf tree cover 30-60%	3,997.31	3.97%
31103 - Broadleaf tree cover 60-100%	24,848.90	24.69%
31203 - Coniferous tree cover 60-100%	26,744.30	26.57%
Sum	**69417**	**68.97%**

GBI Type 6 - Artificial connectivity features:

Ten green bridges, 12 tunnels and 58 motorway bridges were identified on potential ecological linkages, which constitute artificial connectivity features, that assist species movements (see analysis on motorway barriers 4.2.2.).

Artificial barriers:

Artificial areas are a category that do not accommodate a great diversity of species and usually represent barriers.
Additionally to the listed GBI typologies, the following artificial barriers were identified.

Table 15: Artificial barriers

Land use / land cover class	Area [km²]	Percent
11100 - Dense settlement area	15.73	0.02%
12230 – Railway tracks	48.03	0.05%
12210 – Roads, motorways, and trunks	50.88	0.05%
12100 - Industrial and commercial zones	55.90	0.06%
11300 - Built-up area	144.78	0.14%
11000 - Artificial surfaces and constructions	175.66	0.17%
12220 - Road networks	245.38	0.24%
12240 - Unpaved roads and tracks	1,571.74	1.56%
Sum	**2308**	**2.29%**

Summary of GBI elements:
A summary of land use / land cover classifications is provided in the following table.

Table 16: Summary of land use/ land cover classifications on potential regional linkages

Land use / land cover on corridors	Percent
Tree cover	60.9%
Meadows and pastures	14.2%
Cultivated land	13.6%
Scrub and shrubland, sparsely vegetated land, rocks	4.0%
Anthropogenic infrastructure	2.7%
Natural grassland	1.4%
Woody features	1.5%
Wetlands and water bodies	1.2%
Permanent snow	0.2%

7 Summary, highlights, and recommendations for planning

7.1 How to interpret and use the GIS model

The GIS model for ecological connectivity uses the Continuum Suitability Index (CSI) and the evaluation of the main natural areas (SACA1) developed in previous projects. Based on these results, the study seeks to identify potential ecological linkages between areas with the lowest anthropogenic pressure in the Alps, searching for the shortest paths with the fewest and weakest anthropogenic barriers, which can therefore be restored with the least effort. Potentials for restoration are shown by the detailed barrier analysis.

It is following a holistic structural approach with the main assumption that areas with a low degree of human disturbance and areas not modified by humans are of priority for ecological connectivity (Hilty et al., 2020). The model is made for a variety of species on land, considering all terrestrial ecological networks, including forests, grasslands, wetlands, and freshwater systems, and open land in general.

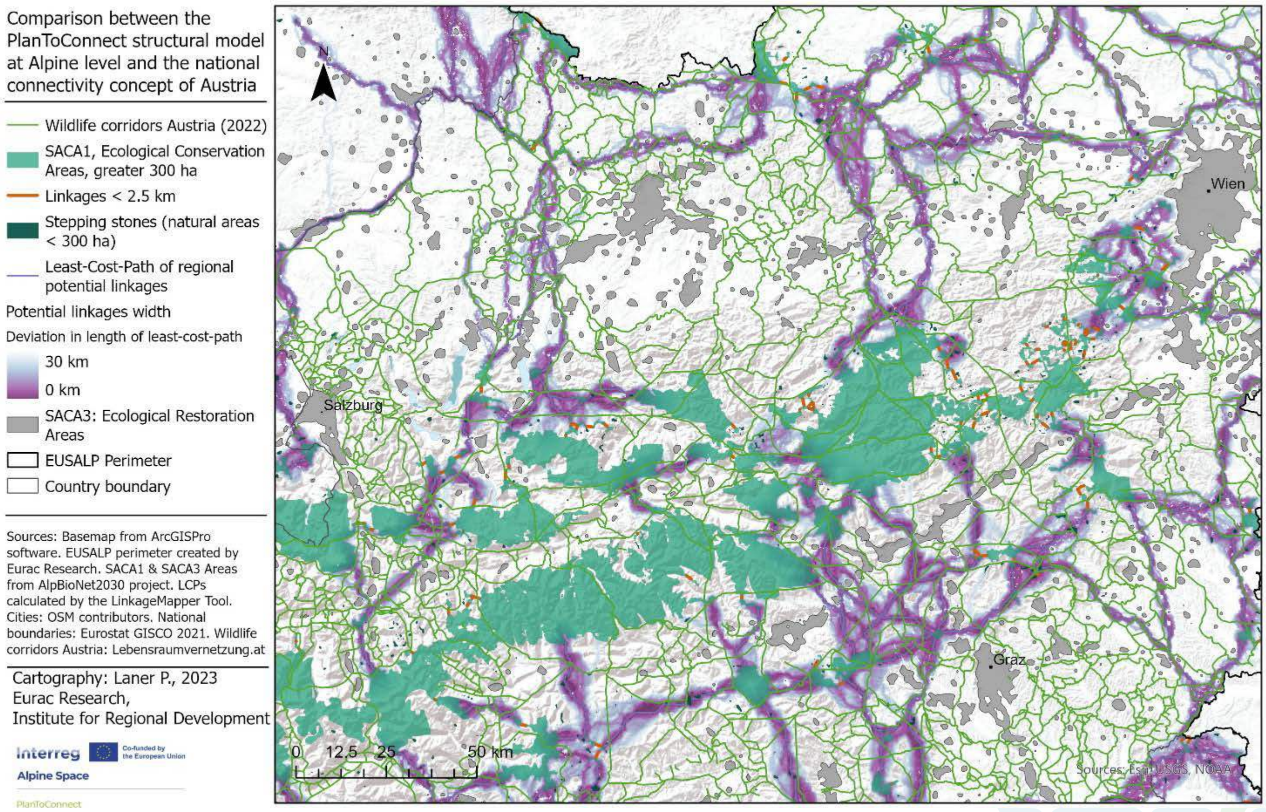
The potential regional linkages simulate the shortest paths between large, highly natural areas, with remaining open green passages between anthropogenic areas. These linkages should be kept open for the unimpeded movement of species and the flow of natural processes that sustain life on Earth (UNEP - CMS, 2020).

The model starts from a structural approach and tries to integrate a variety of habitats. A distinction of types of green infrastructure is happening in a second step.

A validation of the linkages was done by visual interpretation and an overlay of existing national and regional ecological network concepts, which permitted to remove inappropriate least-cost-path mapping by the LinkageMapper programme. The aim was to verify if the protection or restoration of the resulting linkages were realistic. The corrections were limited to obvious cases, e.g., where corridors cross insuperable water bodies (large lakes), settlements, very steep slopes, and very high altitudes. The model was not calculated by a maximum corridor length. However, corridors longer than 13 km were less corresponding to national concepts then shorter corridors.

- The model should be used to identify the priority areas for preservation and restoration of connections between highly natural areas.
- The identified priority areas should not be used as an argument for soil sealing or infrastructure development on other green areas which are not defined as a priority. It should rather be a scenario of important green connections, which are harmonized on an alpine-wide scale. Member states and regional authorities have the possibility to align their spatial ecological network concepts to this proposed model, to create a true ecological network which is required at European level (European Commission, 2022). In this way, conceptual discrepancies can be avoided in spatial planning instruments of different authorities. Disconnected areas due to missing transnational harmonization processes could be restored.

- Important ecological linkages on a more detailed scale e.g., on local level, are not depicted, which does mean that they are not important (see Figure 24).
- The regional corridors of the GIS model are based on dataset of a macro-regional scale with a level of detail of 100x100m or larger and are therefore strongly generalized. On a local level, the exact design of the best green infrastructure connection can have deviations to several hundred of meters. For the exact green infrastructure corridor implementation, more detailed studies and site visits should be conducted.
- The regional linkages should be visualized in combination with the Natura2000 network, which in some cases completes the structure of important linear habitats, contributing to a general ecological connectivity.
- The model had to be adjusted mostly in cases of long- distance linkages, especially in flatland areas and for the consideration of rivers as corridors. It may have gaps for such cases and should be used with caution in these areas. Linkages up to 13 km in length are most appropriate. Only approximately 3% of the linkages shorter than 13km had to be removed by hand because of unappropriated linkage mapping of the LinkgeMapper programme.
- For the facilitation of movements dedicated to certain species, further analysis must be made on a lower scale, possibly with regional or local datasets.



Sources: Basemap from ArcGISPro software. EUSALP perimeter created by Eurac Research. SACA1 & SACA3 Areas from AlpBioNet2030 project. LCPs calculated by the LinkageMapper Tool. Cities: OSM contributors. National boundaries: Eurostat GISCO 2021. Wildlife corridors Austria: Lebensraumvernetzung.at

Cartography: Laner P., 2023
Eurac Research,
Institute for Regional Development

Figure 26: Comparison between the PlanToConnect structural model at Alpine level and the national connectivity concept of Austria

7.2 Highlights

- Not protected SACA1 – areas are mostly present in Switzerland.
- Potential linkages of short – distances < 2.5 km between SACA1 areas have a low level of artificial barriers. Only two motorway barriers and six urban barriers were identified on such potential short – distance connections between SACA1 areas.
- To restore the modelled potential ecological network according to the SACA approach, barriers in SACA3 areas would have to be removed within 160 corridors sections, over a total distance of 238 km. However, additional motorway barriers and urbanisation threats outside SACA3 areas were identified, which must be removed.
- One third of all potential regional linkages are potentially threatened by settlement development and at risk of getting lost. 309 potential ecological linkages are passing through 972 settlement-bottlenecks of less than 300 m.
- 150 motorway barriers were identified on the calculated LCP of regional potential linkages. 114 intersections with motorways show possible wildlife passings, which must be confirmed by more detailed studies and site visits.
- Linkages passing through areas considered as intensive agriculture with more than 3km in length are mostly present in Lower Austria and the whole Po Valley, Italy.
- Shorter corridors passing through intensive agricultural areas are more likely to have linear green elements on the path than potential linkages with long corridor distances in agricultural areas. The reason could be linked to small-scale farming parcels, which are known to be favourable for biodiversity.
- Solar panel fields bigger than 1.000 m² are present on each fifth potential ecological linkage, while only 20 of them are affected in a serious way.

7.3 Recommendations for spatial -, landscape- and transport planning

- Switzerland should focus on the protection of not protected SACA1 areas.
- The protection and restoration of short-distance linkages, smaller than 2.5 km, to create network components is a prerequisite to guarantee that regional potential linkages of the elaborated structural network are functioning. From a structural point of view, there are 25 short distance linkages to protect as soon as possible from further urbanisation and 6 to restore or to clarify alternative routes.
- Restoration measures should be implemented on corridor sections passing through SACA3 areas, which have a high barrier effect, and additionally at identified motorway barriers and bottlenecks due to urbanization processes. Linear corridors, stepping-stone- or landscape corridors on prioritized potential regional linkages should be implemented.
- For spatial planning administrations, which have a big influence to protect the identified linkages from urbanisation and to prevent the loss of linkages, the priority should be on Type 1 and Type 2 linkages. Administrations, which can contribute to dismantle motorway barriers like transport infrastructure offices e.g., the focus should lie on Type 1 and Type 3 linkages, to create a coherent and functioning network. Administrations, which can contribute to expand protected areas on potential linkages should focus also

on Type 1 and Type 3 linkages, to create a coherent network, to keep it together and to connect the inner Alpine arc with major wildlife areas outside the Alps.

- The expansion of solar panel fields or installation of agro-photovoltaic systems on potential linkages should be monitored in respect to ecological connectivity.
- Regional and national administration offices can use the model for harmonization processes along national and regional borders.

8 Scientific and EU policy definitions of technical terms

Ecological connectivity

The term ecological connectivity was developed from the definition of “degree to which landscape facilitates or impedes movement” (Taylor et al., 1993), to a more specific definition of Crooks and Sanjayan, 2006: “Ecological connectivity describes the movement of organisms as gene flow, migration and dispersal of species or processes in a landscape; the more movement there is, the better the connectivity.” For spatial planning purposes, a structural approach for the definition of ecological connectivity, including the spatial dimension is most appropriate. Defining ecological connectivity as “the unimpeded movement of species and the flow of natural processes that sustain life on Earth” (UNEP - CMS, 2020), without consideration of the spatial dimension or the landscape is too broad for the PlanToConnect project. Recent literature regarding ecological connectivity for spatial conservation planning defines connectivity as “the flow of materials, energy, and/or organisms, genes, etc.” across space, which means among habitat patches or regions of interests. “Specifically, ecological connectivity can include propagule dispersal, adult movement, species migrations, species interactions, and ontogenetic linkages, with the associated flows of energy and matter” (Beger et al. 2022).

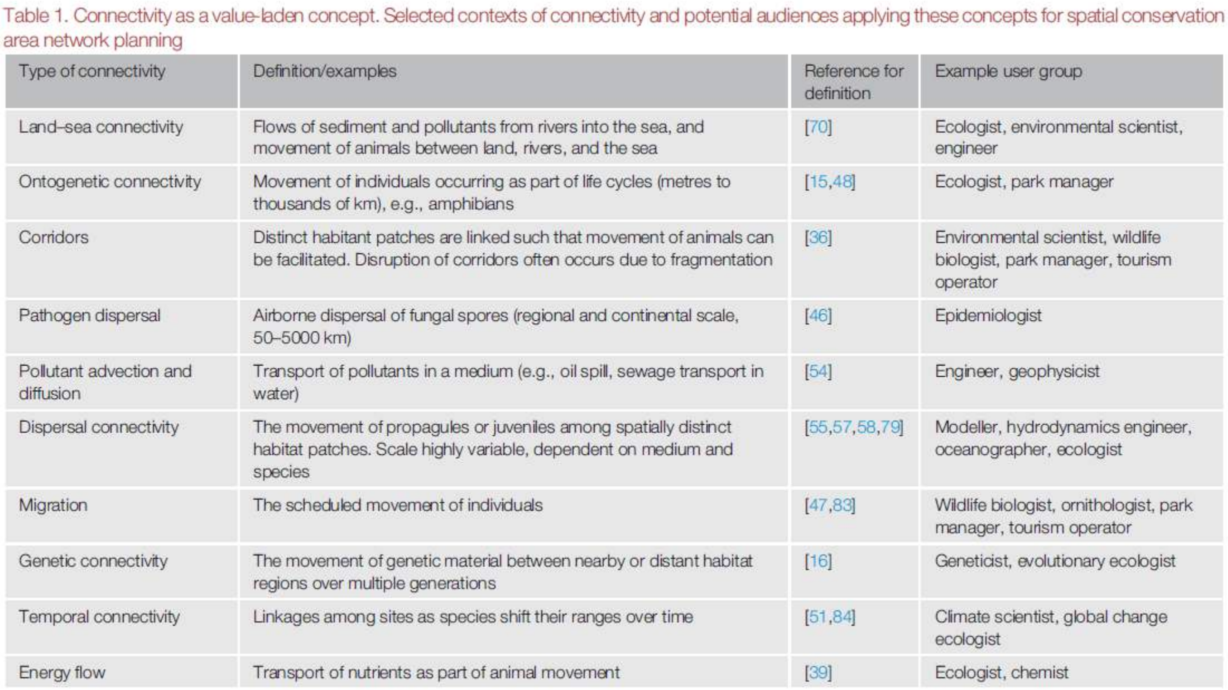


Table 1. Connectivity as a value-laden concept. Selected contexts of connectivity and potential audiences applying these concepts for spatial conservation area network planning

Type of connectivity	Definition/examples	Reference for definition	Example user group
Land–sea connectivity	Flows of sediment and pollutants from rivers into the sea, and movement of animals between land, rivers, and the sea	[70]	Ecologist, environmental scientist, engineer
Ontogenetic connectivity	Movement of individuals occurring as part of life cycles (metres to thousands of km), e.g., amphibians	[15,48]	Ecologist, park manager
Corridors	Distinct habitant patches are linked such that movement of animals can be facilitated. Disruption of corridors often occurs due to fragmentation	[36]	Environmental scientist, wildlife biologist, park manager, tourism operator
Pathogen dispersal	Airborne dispersal of fungal spores (regional and continental scale, 50–5000 km)	[46]	Epidemiologist
Pollutant advection and diffusion	Transport of pollutants in a medium (e.g., oil spill, sewage transport in water)	[54]	Engineer, geophysicist
Dispersal connectivity	The movement of propagules or juveniles among spatially distinct habitat patches. Scale highly variable, dependent on medium and species	[55,57,58,79]	Modeller, hydrodynamics engineer, oceanographer, ecologist
Migration	The scheduled movement of individuals	[47,83]	Wildlife biologist, ornithologist, park manager, tourism operator
Genetic connectivity	The movement of genetic material between nearby or distant habitat regions over multiple generations	[16]	Geneticist, evolutionary ecologist
Temporal connectivity	Linkages among sites as species shift their ranges over time	[51,84]	Climate scientist, global change ecologist
Energy flow	Transport of nutrients as part of animal movement	[39]	Ecologist, chemist

Source: (Beger et al. 2022)

Structural and functional connectivity

According to Godron & Forman (1983), Taylor et al. (1993) and Pierik et al. (2016) (in Favilli, Hoffmann, Ravazzoli, 2017) the structural and functional connectivity can be defined and distinguished in such a way:

Structural connectivity, also called landscape connectivity, is purely referring to physical conditions of the territory (space/landscape), and is solely influenced by factors like land use, topography, level of fragmentation, the presence of infrastructure (see also Favilli et al., 2023; Favilli et al., 2015).

Functional connectivity, so-called species- specific connectivity, refers to the behaviour of the investigated species to environmental conditions. This is solely influenced by ecological necessities of the species and their behaviour. This is a concept which firstly came up in the 80ies and which is developed by a high number of scientific studies.

For functional connectivity a lot of information as well as monitoring is required about the selected target species (specific habitat requirements, dispersal behaviour, population dynamics, etc.). Analysing a high number of target species can be time consuming. Another disadvantage is the focus on one or a few species, which do not represent the whole biodiversity. Apart from the consideration of umbrella species, measures that support connectivity for a single species are not necessarily beneficial for others. “As only some 20% of the global extant species richness has been identified, an understanding of species richness is mostly limited to the most common taxa (Kim and Byrne, 2006)” (Luethi 2019, not published).

The basis of spatial planning are natural, semi-natural and artificial physical structures. Therefore, the PlanToConnect project proposes to focus on structural connectivity rather than functional connectivity. This means looking at physical structures (various habitats) rather than individual species and their spatial distribution.

The IUCN Guidelines for Ecological Connectivity describes structural connectivity more in detail as “a measure of habitat permeability based on the physical features and arrangements of habitat patches, disturbances, and other land, freshwater or seascape elements presumed to be important for organisms to move through their environment (Hilty et al., 2020). Structural connectivity modelling aims to identify areas through which a variety of species may be able to move. Models often prioritise ecological corridors characterised by a low degree of human modification – areas which are assumed to be permeable to species sensitive to human disturbance (Dickson et al., 2017). In addition, linear areas that provide connectivity, such as river corridors, ocean currents or linear forest fragments, can be identified and prioritised for conservation (e.g., Rouget et al., 2006).” (Hilty et al., 2020).

“*Various connectivity concepts were proposed and tested, including the ecological network concept (Hilty et al., 2006), consisting of core areas, corridors and buffer areas. The green infrastructure concept of the European Union is based on these concepts and does also include additional elements such as steppingstones (e.g. Kramer-Schadt et al., 2011; Saura et al., 2014).*” (Luethi 2019). The green and blue infrastructure concept is used as a tool to achieve ecological connectivity (see definition on Green and Blue Infrastructures).

Ecological corridors/ linkages

"A clearly defined geographical space that is governed and managed over the long term to maintain or restore effective ecological connectivity. The following terms are often used similarly: 'linkages', 'safe passages', 'ecological connectivity areas', 'ecological connectivity zones', and 'permeability areas." […] "'Clearly defined' means a spatially defined area with agreed and demarcated borders." (Hilty et al., 2020).

Connectivity conservation area

Connectivity conservation area is a generic term introduced in recent scientific literature for land/sea areas actively managed for connectivity conservation (Worboys et al., 2010, p. 4). The intention is to use 'connectivity conservation area' (or simply connectivity area) to avoid confusion with other related terms, such as 'protected area', and also to distinguish the field and its broader scope from the original uses of the term corridor which were more linear and focussed on wildlife, principally animal populations. Today, the term corridor continues to be an important spatial tool, among a suite of tools being developed, to support connectivity conservation.

Large scale connectivity

"On a large spatial scale, connectivity areas facilitate the migrations of animals between breeding and wintering areas, or over daily, seasonal, and annual time-frames, even if no protected areas are specifically established for their habitat (Marra et al., in Crooks and Sanjayan, 2006, ch. 7). Hydrologic connectivity transfers matter, energy and organisms through the medium of water within or between elements of the hydrologic cycle. These functions are critical for maintaining the biological integrity of ecosystems and providing water and other ecosystem services for peoples." (Ricketts et al., in Crooks and Sanjayan, 2006, ch. 11).

Small scale connectivity

"On a smaller scale, connectivity conservation provides important biodiversity benefits for local areas. Hedgerows, forest belts around agricultural fields, and patches of natural vegetation interspersed in semi-developed areas are examples of connectivity conservation measures which provide habitat for locally important species (birds, butterflies, amphibians) and local ecosystem services. For example, the dominant crop pollinators worldwide are bees, which rely on natural connectivity among different habitat types, particularly floral habitats." (ibid.)

Protected area

"A protected area is a clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long term conservation of nature with associated ecosystem services and cultural values". (IUCN, 2008)

9 GIS data sources

Agricultural areas:

Marsoner, Thomas; Simion, Heidi; Giombini, Valentina; Vigl, Lukas Egarter; Candiago, Sebastian (2023). A detailed land use/land cover map for the European Alps macro region. figshare. Collection. EUSALP LULC map 2020. https://doi.org/10.6084/m9.figshare.c.6357056.v1

EEA (2020 b), Corine Land Cover (CLC) 2018, Version 2020_20u1, downloaded from https://land.copernicus.eu/pan-european/corine-land-cover/clc2018?tab=download, in April 2021

Built-up areas:

Esri, (2022). ArcGIS Living Atlas of the World. Sentinel-2 10m Land Use/Land Cover dataset, 2022, downloadable from https://livingatlas.arcgis.com/landcoverexplorer/#mapCenter=-83.21%2C34.332%2C4&mode=step&timeExtent=2017%2C2021&year=2017&downloadMode=true

Ecological networks:

Austria:

Lebensraumvernatzung.at (2022). Geodatenkatalog Lebensraumvernetzung. LRVA-2022: Aktuelle Version der Lebensraumkorridore Österreich (Version 2022-10-16). https://lebensraumvernetzung.at/de/geodata

France:

Inventaire National du Patrimoine Naturel, (2023). La Trame verte et bleue. Layer “couche nationale des corridors surfaciques". https://inpn.mnhn.fr/programme/trame-verte-et-bleue/donnees-srce

Germany:

National Office for Nature Protection, (2023). Data request to the National Office for Nature Protection of Germany (Bundesamt für Naturschutz). Bundeskonzept grüne Infrastruktur. BKGI_2023.

Italy:

GeoCatalogo Alto Adige (2023). Ricerca per categoria. Dati di base e pianificazione. Pianificazione e catasto. http://geokatalog.buergernetz.bz.it/geokatalog/#!

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Regione Lombardia (2011). Geoportale della Lombardia. Metadati. Rete Ecologica Regionale (RER). https://www.geoportale.regione.lombardia.it/metadati?p_p_id=detailSheetMetadata_WAR_gptmetadataportlet&p_p_lifecycle=0&p_p_state=normal&p_p_mode=view&_detailSheetMetadata_WAR_gptmetadataportlet_identifier=r_lombar%3A6c25a13d-e6e2-4fc0-9538-9866145908b0&_jsfBridgeRedirect=true

Slovenia:

Penko Seidl, N., Bevk, T., Golobič, M., Jerina, K., Bordjan, D., (2021). Definition of ecological corridors at SI level as a support for spatial development planning and management of nature and other resources - final report. University of Ljubljana – Biotechnical Faculty. Data request 2023.

Switzerland:

BAFU, (2023). Biodiversität: Geodaten. REN (Nationales ökologisches Netzwerk, 1:100'000), Wildtierkorridore Überregional. https://www.bafu.admin.ch/bafu/de/home/themen/biodiversitaet/zustand/karten/geodaten.html

Lakes:

EuroGeographics, (2022). EuroGlobalMap release 2022. Pan-European Database at Small Scale. https://eurogeographics.org/products-and-services/open-data/, Date of last revision and publication: 31.01.2022.

Motorways and railways:

EuroGeographics, (2022). EuroGlobalMap release 2022. Pan-European Database at Small Scale. https://eurogeographics.org/products-and-services/open-data/, Date of last revision and publication: 31.01.2022.

Protected areas:

UNEP-WCMC and IUCN, (2022), Protected Planet: The World Database on Protected Areas (WDPA), Cambridge, UK: UNEP-WCMC and IUCN. Available at: www.protectedplanet.net

SACA1, SACA2, SACA3 areas, Continuum Suitability Index:

Swiss National Park (2019). SACA1, SACA2, SACA3, CSI22111, version 2019. Interreg Alpine Space ALPBIONET2030 project. Repository of the Swiss National Park.

Topography:

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Annexes

Annex 1: List of protected area designations from the WDPA

Areas considered as protected:

- Biosphere Park
- Biotope Protection Order
- Core Zone
- Ecological Development Area
- Ex-Lege Landscape Protection
- Federal Hunting Reserves
- Federal Inventory of Alluvial Zones of National Importance
- Federal Inventory of Amphibian Spawning Areas of National Importance
- Federal Inventory of Dry Grasslands and Pastures of National Importance
- Federal Inventory of Fenlands of National Importance
- Federal Inventory of Raised and Transitional Mires of National Importance
- Federal Inventory of Reserves for Waterbirds and Migratory Birds of International And National Imp.
- Flora Protection Area
- Forest Integral Biological Reserve
- Forest Managed Biological Reserve
- Forest Reserves
- Horticultural Monument
- Land Acquired by A Regional Conservatory of Natural Areas
- Land Acquired by Conservatoire Du Littoral (National Seaside and Lakeside Conservancy)
- Landscape And Nature Protection Area
- Landscape Park
- Landscape Protection Area
- National Hunting and Wildlife Reserve
- National Nature Monument
- National Nature Reserve
- National Park
- National Park - Buffer Zone/Area of Adhesion
- National Park - Core Area
- National Park - Integrale Reserve
- Natural Monument
- Nature Monument
- Nature Park
- Nature Reserve
- Other Protected Natural Regional Areas
- Private Nature Reserves

- Protected Area
- Protected Biotopes
- Protected Forest
- Protected Habitat
- Protected Landscape Area
- Protected Landscape Area; Second Level of Protection
- Protected Landscape Section
- Protected Natural Objects of Local Importance
- Protected Perimeter Around a National Nature Reserve
- Protected Site / Private Protected Site
- Ramsar Site, Wetland of International Importance
- Ramsar Sites
- Regional Nature Park
- Regional Nature Reserve
- Regional Park
- Regional Protected Areas
- Regional/Provincial Nature Park
- Regional/Provincial Nature Reserve
- Rest Area
- Significant Landscape
- Special Conservation Areas
- Special Purpose Forest
- Specially Protected Area
- State Nature Reserve
- Strict Nature Reserve
- Swiss National Park
- UNESCO-MAB Biosphere Reserve
- Wilderness Area
- World Heritage Site (natural or mixed)

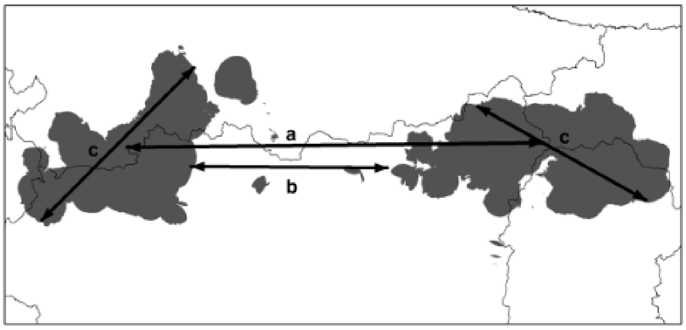
Areas excluded from the protection status:

- Emerald Network
- Site of Community Importance (Habitats Directive)
- Special Protection Area (Birds Directive)
-

Annex 2: Processes in ArcGIS Pro to create SACA1 components

Conducted steps in ArcGIS:

- The “Generate near table” function connects the periphery of the two ranges (line “b” in the figure below)
- With the “XY To Line tool”, a polyline was created in ArcGIS and buffer in a second step with a very small buffer (1m) to create a polygon.
- The polygons of SACA1 areas were merged, dissolved by a buffer function, and split up into Singlepart features.
-



-

Figure 27: periphery of the two core areas (line b)

Source: Mateo-Sánchez et al. 2015

Table 17: Characteristics of network components according to their size

	Number of components	Area [ha]	Percent of area	Comment on test run
SACA1 total	7.129	4,896,546	100.0%	
SACA1 >= 100 ha	1772	4,780,681	97.6%	
SACA1 >100 ha, components within 2.5km, without large lakes	751	4,746,063	96.9%	Test run not feasible due to too extensive calculation times. More than 2.000 potential linkages.
SACA1 >100 ha, components within 2.5km > 300 ha, without large lakes	459	4,695,161	95.9%	1428 sticks between adjacent SACA1 areas identified. Only 4,1% of SACA1 areas were neglected in the calculation. 2% of all SACA1 areas, bigger than 100 ha, are neglected.

Annex 3: Characteristics of cost-weighted distances

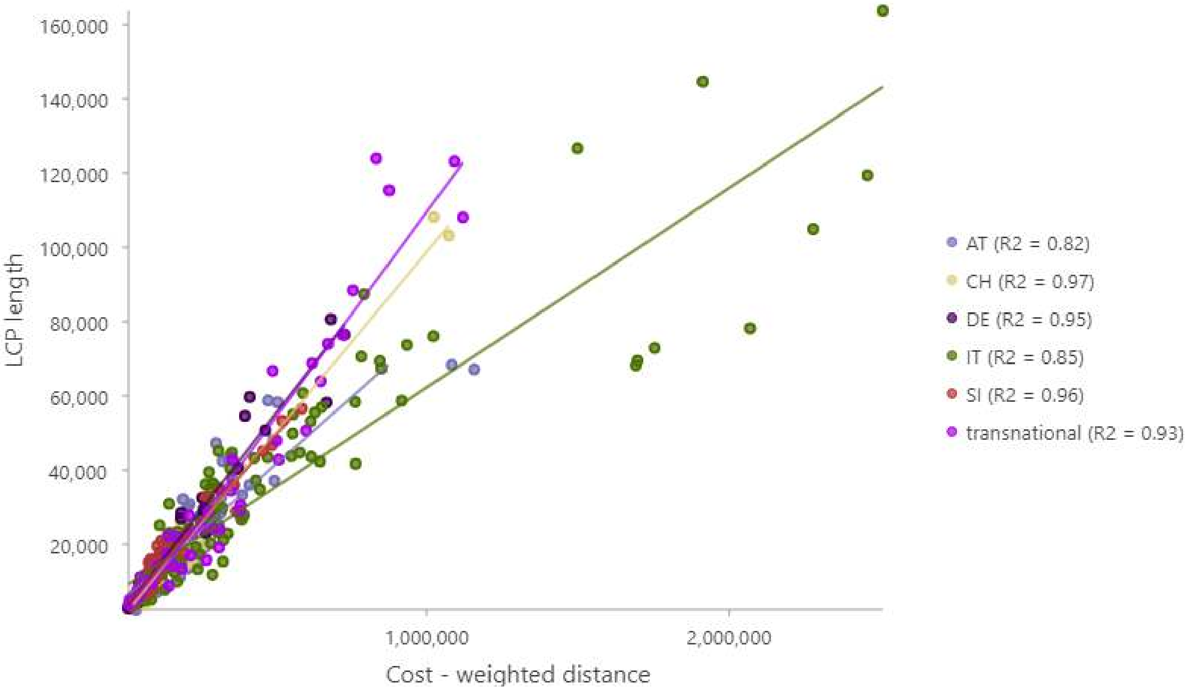


Figure 28: Relationship between cost-weighted distance and LCP length by country

The longer the path, the higher is the cost-weighted distance.

Following figures are showing that the more barriers or bottlenecks are on the path, the higher is the cost-weighted distance.

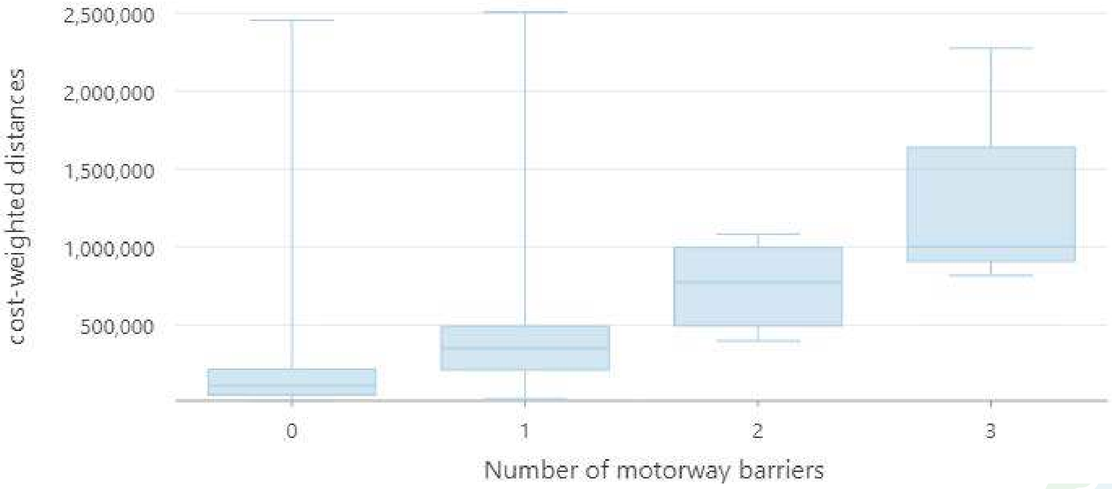


Figure 29: Distribution of cost-weighted distances by number of motorway barriers on the path

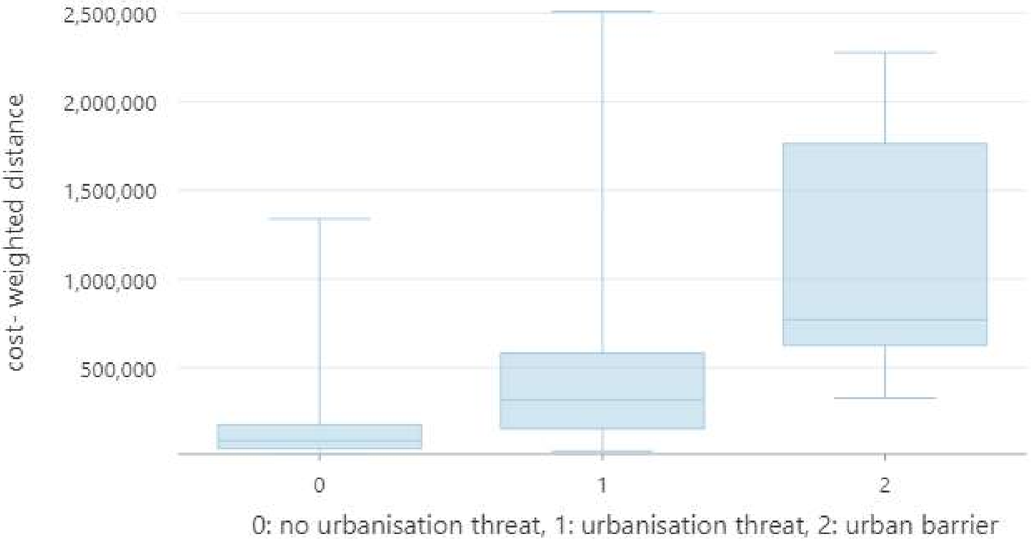


Figure 30: Distribution of cost - weighted distance by urbanisation threat

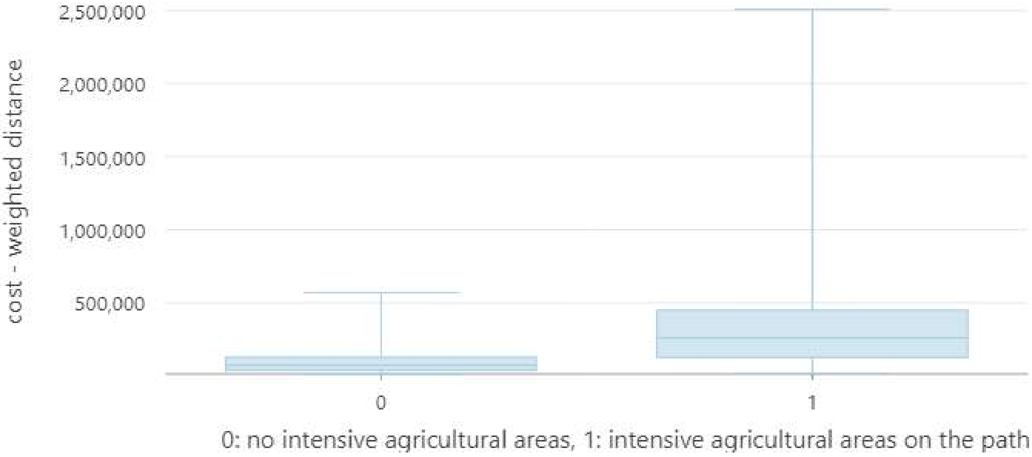
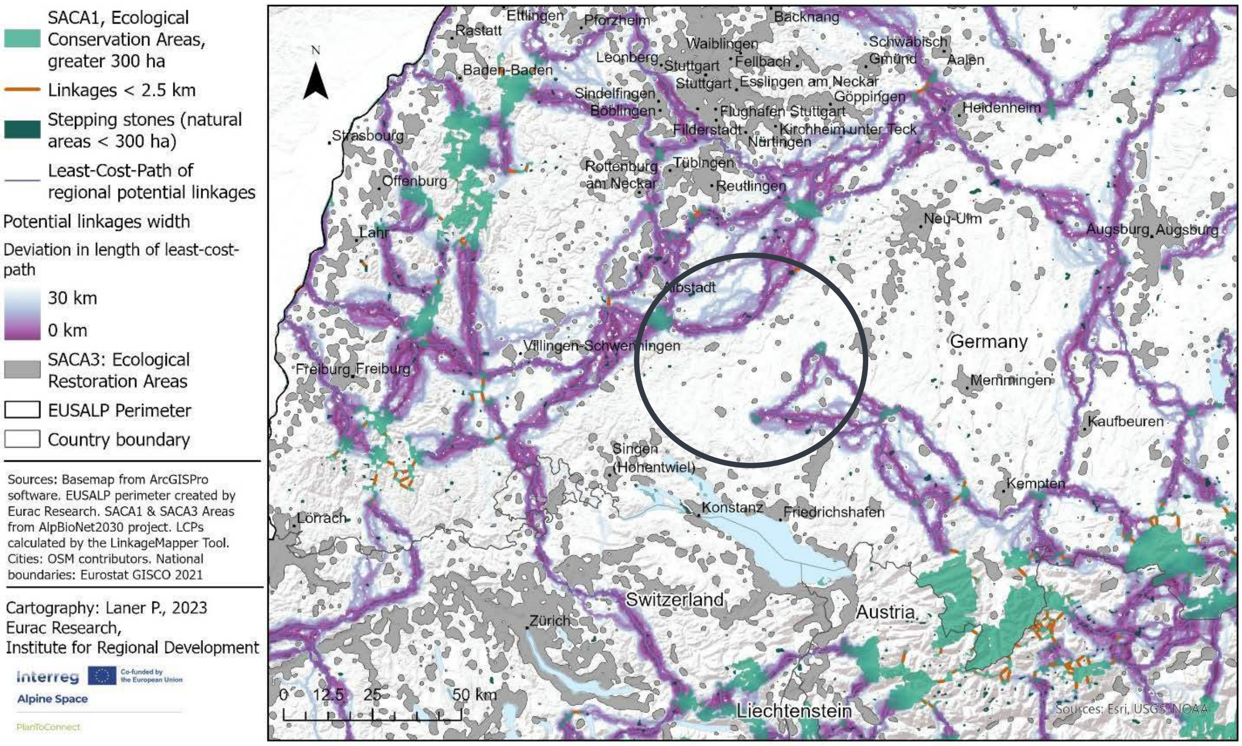


Figure 31: Distribution of cost - weighted distance by existence of intensive agriculture passages

Annex 4: Inconsistencies of the model



Sources: Basemap from ArcGISPro software. EUSALP perimeter created by Eurac Research. SACA1 & SACA3 Areas from AlpBioNet2030 project. LCPs calculated by the LinkageMapper Tool. Cities: OSM contributors. National boundaries: Eurostat GISCO 2021

Cartography: Laner P., 2023
Eurac Research,
Institute for Regional Development

Figure 32: Inconsistency in Germany

Mapping report of priority connectivity areas for spatial planning and GBI typology catalogue

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Asters, organisation for the conservation of natural areas in Upper Savoy (FR)
Eurac Research (IT)
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