Interreg CENTRAL EUROPE
European Union European Regional Development Fund
MaGICLandscapes

MANUAL OF GREEN INFRASTRUCTURE FUNCTIONALITY ASSESSMENT

Decision Support Tool

TECHNISCHE UNIVERSITÄT DRESDEN

VÚKOZ

Sächsische Landesstiftung Natur und Umwelt Akademie

Leibniz Institute of Ecological Urban and Regional Development

universität wien

Nationalpark Thayatal

TORINO METROPOLI Città metropolitana di Torino

ENEA

MANUAL OF GREEN INFRASTRUCTURE FUNCTIONALITY ASSESSMENT – DECISION SUPPORT TOOL

This English manual version was compiled as Output O.T2.1 of the Interreg Central Europe Project MaGICLandscapes "Managing Green Infrastructure in Central European Landscapes" funded by the European Regional Development Fund (ERDF). This publication is also available in Czech, German, Italian and Polish languages and can be downloaded from the **project website**.

Lead Partner:
Technische Universität Dresden
Faculty of Environmental Sciences
Chair of Remote Sensing, Prof. Dr. Elmar Csaplovics
Helmholtzstr. 10
01069 Dresden

Authors of this Manual:
Florian Danzinger[7], Mita Drius[7], Stefan Fuchs[7], Thomas Wrbka[7], Christopher Marrs[1], Anke Hahn[1], Simonetta Alberico[9], Gabriele Bovo[9], Simone Ciadamidaro[10], Martin Erlebach[6], David Freudl[8], Stefania Grasso[9], Zygmunt Jała[4], Henriette John[5], Mariarita Minciardi[10], Marco Neubert[5], Gian Luigi Rossi[10], Hana Skokanová[2], Tomáš Slach[2], Sven Riedl[3], Paola Vayr[9], Dorota Wojnarowicz[4]

1 **Technische Universität Dresden, Germany**

2 **Silva Tarouca Research Institute for Landscape and Ornamental Gardening, Czech Republic**

3 **The Saxony Foundation for Nature and Environment, Germany**

4 **Karkonosze National Park, Poland**

5 **Leibniz Institute of Ecological Urban and Regional Development, Germany**

6 **The Krkonoše Mountains National Park, Czech Republic**

7 **University of Vienna, Austria**

8 **Thayatal National Park, Austria**

9 **Metropolitan City of Turin, Italy**

10 **ENEA - Italian National Agency for New Technologies, Energy and Sustainable Economic Development, Italy**

Editors: Florian Danzinger, Mita Drius, Stefan Fuchs, Thomas Wrbka, Christopher Marrs
Layout: Anke Hahn
Cover Illustration: **Anja Maria Eisen**

Suggested Citation: *Danzinger, F., Drius, M., Fuchs, S., Wrbka, T., Marrs, C. (Ed., 2020). Manual of Green Infrastructure Functionality Assessment – Decision Support Tool. Interreg Central Europe Project MaGICLandscapes. Output O.T2.1, Vienna. With contributions from: F. Danzinger, M. Drius, S. Fuchs, T. Wrbka, C. Marrs, S. Alberico, G. Bovo, S. Ciadamidaro, M. Erlebach, D. Freudl, S. Grasso, Z. Jała, H. John, M. Minciardi, M. Neubert, G.L. Rossi, H. Skokanová, T. Slach, S. Riedl, P. Vayr, D. Wojnarowicz. Published online: https://www.interreg-central.eu/Content.Node/MaGICLandscapes.html#Outputs*

Vienna, February 2020

Contents

1 Introduction and Aim of this Manual

This Manual of Green Infrastructure Functionality Assessment is the main output of the Work Package 2 outputs, which were developed as part of the Interreg Central Europe project MaGICLandscapes - Managing Green Infrastructure in Central European Landscapes.

It is designed to be a tool that guides the reader through the process of undertaking a green infrastructure (GI) assessment on a regional and local scale in central Europe. It will demonstrate using practical examples which are the main steps to conduct a GI functionality assessment, starting from the regional discrepancies in the definition of GI, then shifting to the description of how and why particular datasets are more useful in conducting such assessments at this level. Finally, it will then show through various spatial analyses how a map of regional and local GI functionality can be built.

The description of the assessment and mapping process presented by this manual is meant to provide decision support to other users that want to fulfil similar tasks.

The manual describes at first the general procedure for assessing GI functionality. After a short introduction to GI definitions and ambiguities in the terminology at local/regional level, the available spatial data for assessing GI and Blue Infrastructure (BI) in central Europe are presented and discussed. Subsequently, the main methodologies employed to perform the GI functionality assessment are reported. They are the connectivity analysis (see 3.3.1), the field mapping methodology testing (see 3.3.2) and the functionality analysis (see 3.3.3). The general and specific findings of this assessment process are then presented. Each step of the functionality assessment is explained by maps from the case study areas of the project (see 3.3.3.2). Finally, we draw conclusions and provide suggestions about the functionality assessment.

The benefit of assessing and analysing these data is the acquisition of knowledge about spatial distribution and quality of GI on a regional and local level. The findings of this manual help to identify hot spots of GI networks as well as GI with a high functional value or areas with a lack of such elements.

This valuable data, visualised in maps, is the basis for planning further actions. Using these results, concrete measures on different scales for the regions GI can be developed, in order to maintain the present structures as well as the sustainable use of land and to expand the network of GI within protected areas but also beyond their borders. Thus, the management of GI does not only change the landscape for the better from an ecological and nature conservation perspective, it also ensures many landscape services from which humans benefit or actually depend on.

2 General Procedure of Green Infrastructure functionality assessment and mapping

Green infrastructure (GI) in spatial planning needs to cover many different policy sectors and its implementation is an on-going process dependent on political willingness. To date, tools for implementing the assessment of the multi-functionality of GI elements are still under progress. Examples of development of toolsets for the assessment of GI multifunctionality include the combination of spatial data with the knowledge of experts and regional and local actors (Kopperoinen et al. 2014), the creation of performance indicators of GI (Pakzad and Osmond 2016), and the use of field questionnaire surveys to explore the perceived benefits (e.g. Qureshi et al. 2010). Nevertheless, a holistic or combined approach to address the functionality assessments is rarely employed to date.

The following steps in the procedure of green infrastructure functionality assessment and mapping are explained in this manual:

1. Definition of Green and Blue Infrastructure elements representing the objects of interest at regional level
2. Data acquisition at the transnational, regional and local level
3. Generating transnational, regional and local maps of GI functionality for the case study areas (CSA)
    - Connectivity analysis
        - MSPA (Morphological Spatial Pattern Analysis)
        - Network analysis
        - Euclidean Distance
    - Field mapping methodology
        - Identification of elements of GI on the local level
            - EUNIS habitat classification
            - determination of hemerobiotic state or the level of naturalness
            - Mapping of barriers
    - Functionality analysis
        - Preparation of landscape service capacity matrix
        - Individual expert-based revision
        - Final matrix based on joint consensus discussion
        - Maps demonstrating functionality at regional level

The results can be used to inform the following target groups about the functionality assessment methodology of GI:

- General public (to raise awareness),
- Policy decision-makers (to take measures to protect and to enhance the GI Network) and
- Planning sector (to implement measures and to draft Strategies and Action Plans).

3 Generating a Regional Green Infrastructure Functionality Map – Lessons from MaGICLandscapes

3.1 Definition of Green and Blue Infrastructure elements representing the objects of interest at regional level

As already described in the MaGICLandscapes 'Green Infrastructure Handbook - Conceptual & Theoretical Background, Terms and Definitions' (John et al. 2019) we suggest the green (and blue) infrastructure definition of the European Commission (2016):

"Green infrastructure is a strategically planned network of ***natural and semi-natural areas*** *with other environmental features designed and managed to deliver a wide range of ecosystem services such as water purification, air quality, space for recreation and climate mitigation and adaptation. This network of* ***green (land) and blue (water) spaces*** *can improve environmental conditions and therefore citizens' health and quality of life. It also supports a green economy, creates job opportunities and enhances biodiversity. The* ***Natura 2000 network*** *constitutes the backbone of the EU green infrastructure"* (EC 2016).

In the transnational mapping phase of MaGICLandscapes different datasets able to spatially describe green and blue infrastructure (GI and BI) were explored. From the available dataset sources the standardised land cover classification CORINE Land Cover (CLC 2012) was considered the most adequate (see Neubert and John 2019) for further details. According to the CLC classification we could identify 44 CLC classes that either represent GI elements, could contain GI elements under specific circumstances or could not be regarded as GI. The final transnational map of GI based on CLC classes arising from the expert-based consultation within the transnational mapping is shown in Figure 1 (Neubert and John 2019).

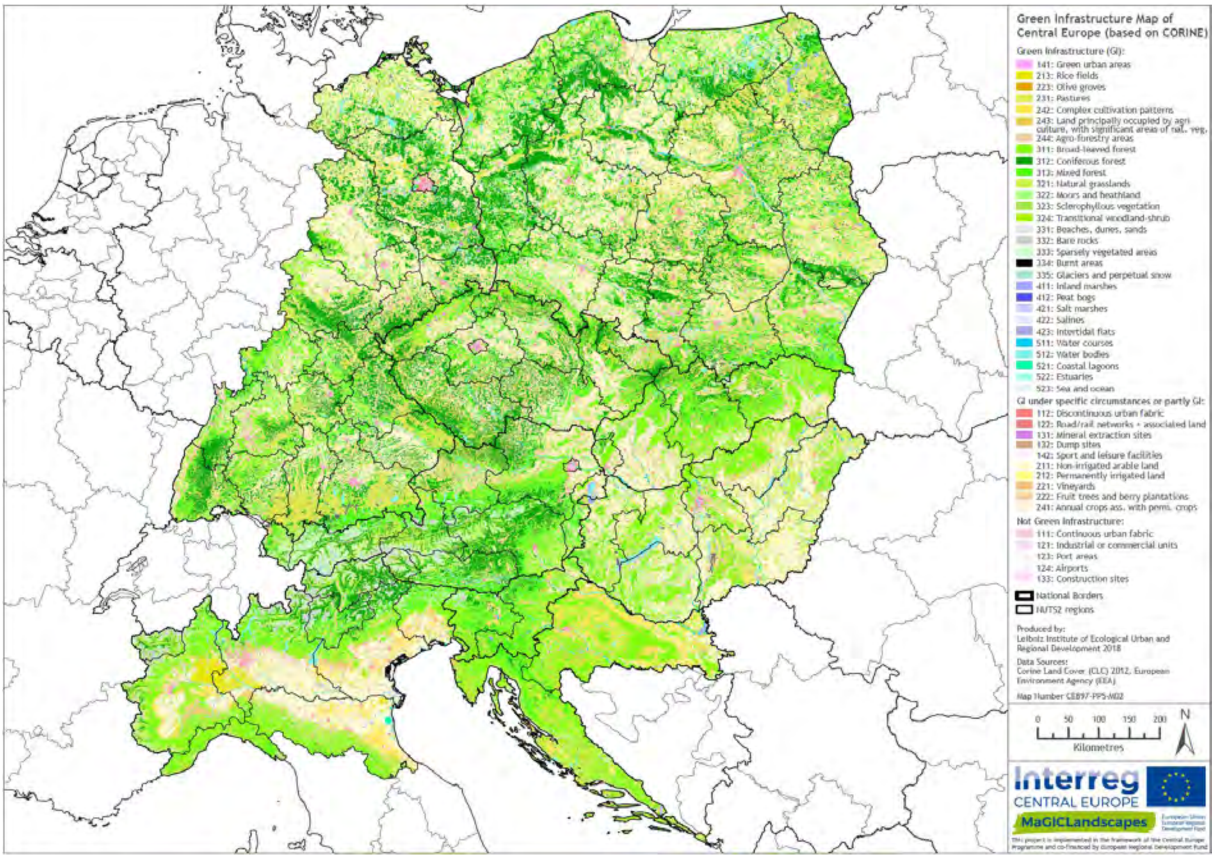

Figure 1: Map of green infrastructure for the Central Europe Programme Area based on the transnational legend using CORINE Land Cover (CLC) data from 2012.

Based on the findings of the transnational mapping, we carried out an analysis to define GI at regional level. We chose three categories to distinguish and categorise the CLC classes into GI elements: *"GI"* for classes belonging to GI, *"not GI"* for classes not belonging to GI, and *"partly GI"* for classes which may contain GI elements or could be considered as GI under specific circumstances.

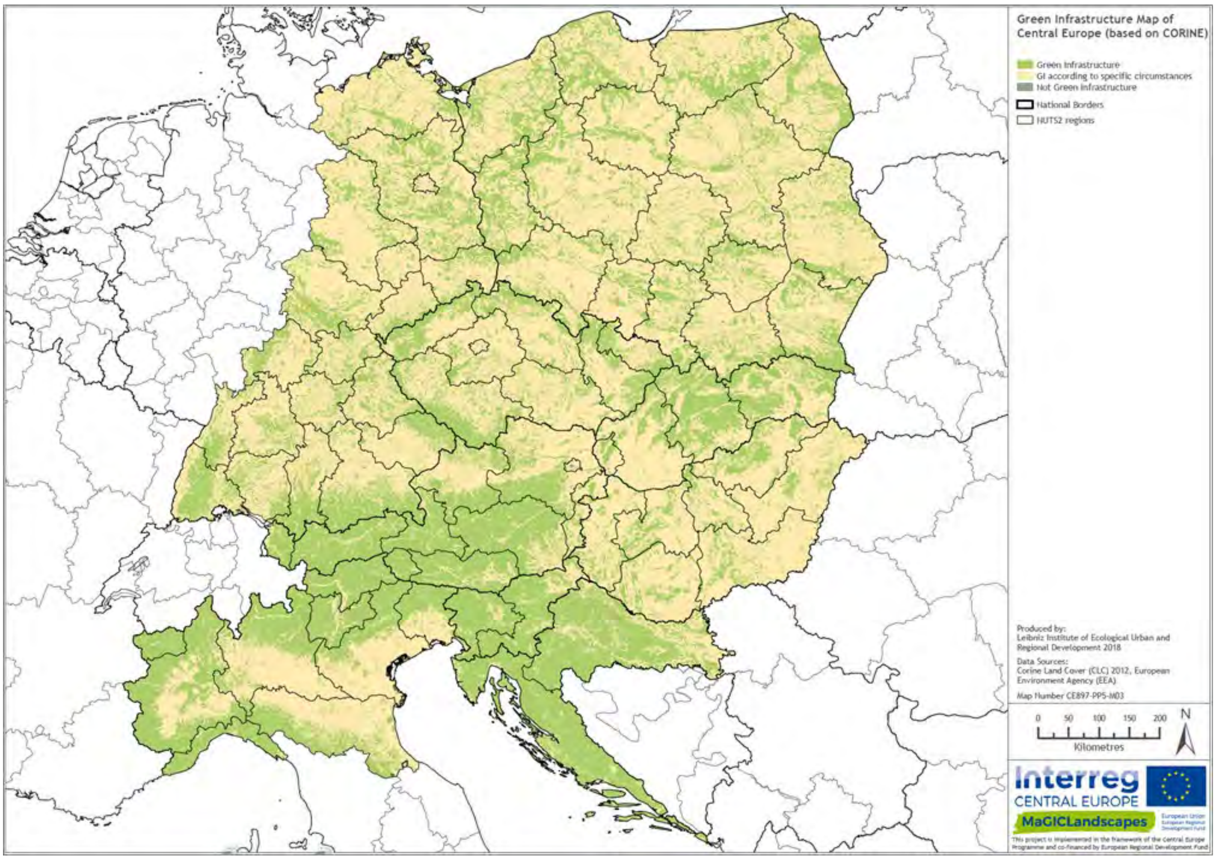

Figure 2: Map of green infrastructure for the Central Europe programme area based on the transnational legend using CORINE land cover data from 2012. The CORINE classes are classified in a simplified transnational legend just three classes (GI, GI under specific circumstances or partly GI, not GI) based on the coordinated legend

Since some of the GI definitions did not fit to the regional landscape characteristics, the project partners were asked to provide their local definition of GI and to indicate which CLC classes are part of GI according to this definition for their respective CSAs (Figure 3). The partners provided their definitions and deviations from the transnational GI based on the features of case study areas located in very diverse landscapes and characterised by different landscape features. The results of the regional classifications of GI are shown in Table 1 and Table 2.

These regional definitions of GI are very dependent on the available spatial and thematic resolution of geodata for technical reasons on the one hand and the current predominant land use, the intensity of management and general landscape characteristics on the other hand (Table 2).

All partners excluded the artificial CLC classes from GI, differently from the transnational GI classification, where *"Discontinuous urban fabric"* and *"Road and rail networks and associated land"* were categorized as *"partly GI"*. In the regional context of the case study area Po Hills around Chieri (IT) some classes of GI elements differed from the classification proposed on transnational scale. For instance, sports facilities usually have an artificial surface and thus are not belonging to GI. Unlike this they considered the CLC classes *"Mineral extraction sites"* and *"Dump sites"* as GI, because they are located along the River Po or are no longer used and thus re-naturalised, respectively. The German partners from the Dübener Heide case study area included *"Annual crops associated with permanent crops"* in the GI network, due to naturalness level recorded in their case study area. In the Krkonoše National Park and the Tri-Border Area (CZ, DE, PL), fruit trees and berry plantations are considered at least partly as effective GI elements, because of their positive contribution to the connectivity of the agrarian landscape. On the other hand, elements like *"Mineral extraction sites"* and *"Non-irrigated arable land"* are excluded from the regional GI conceptualisation, because of the predominance of anthropogenic infrastructure and the level of management of agriculture, respectively. On the contrary, the Austrian project partners consider the class *"Sport and leisure facilities"* as GI, because in their view golf courses and lawns offer a positive contribution to the network of GI.

Despite these differing initial conditions all case study areas were able to perform a highly comparable analysis and to produce consistent results, which shows that the proposed methodology allows for a universal application across varied landscapes.

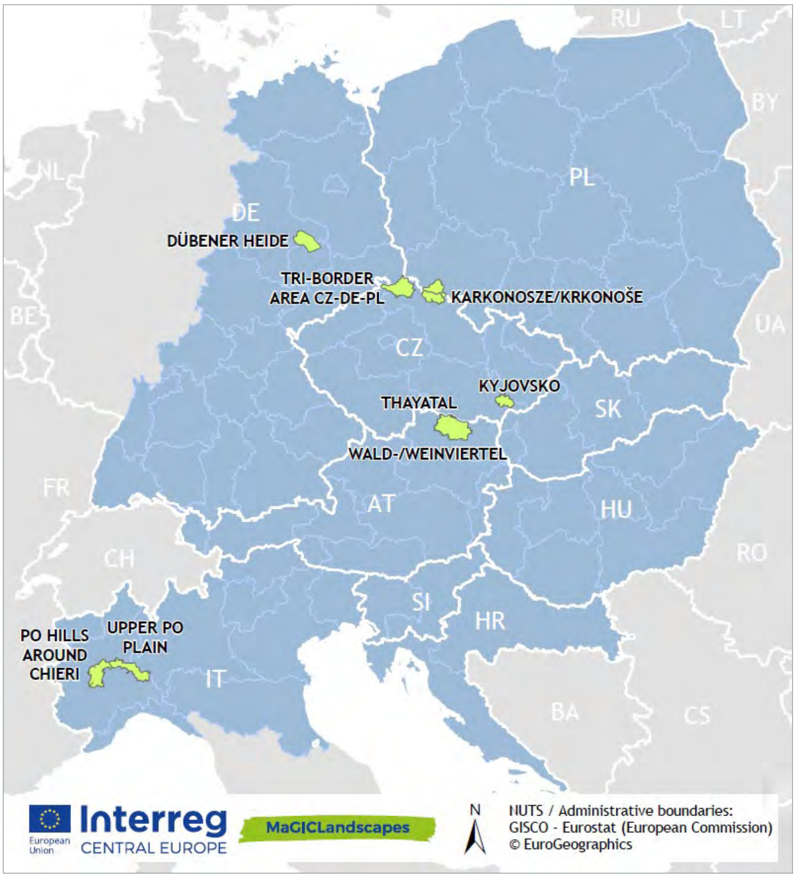

Figure 3: Map of Central Europe (blue area) with the nine case study areas (green) of the MaGICLandscapes project.

Table 1: Transnational GI classification based on CLC and acceptations/rejections from the project partners for their respective case study area. The red colour highlights the category "not GI", whereas the yellow colour expresses the discrepancies revealed for the category "partly GI". The green colour stands for "GI". (N/A = not applicable)

CLC code	CLC description	Transnational GI definition	Tri-Border Area (CZ, DE, PL)	Krkonoše Mountains National Park (CZ)	Karkonosze National Park (PL)	Kyjovsko (CZ)	Eastern Waldviertel & Western Weinviertel (AT)	Thayatal National Park (AT)	Upper Po Plain (IT)	Po Hills around Chieri (IT)	Dübener Heide Nature Park (DE)
111	Continuous urban fabric	**not GI**	not GI	not GI	not GI	not GI	not GI	not GI	not GI	not GI	not GI
112	Discontinuous urban fabric	**partly GI**	not GI	not GI	partly GI	not GI	not GI	not GI	not GI	not GI	not GI
121	Industrial or commercial units	**not GI**	not GI	not GI	not GI	not GI	not GI	not GI	not GI	not GI	not GI
122	Road and rail networks and associated land	**partly GI**	not GI	not GI	not GI	not GI	not GI	not GI	not GI	not GI	not GI
123	Port areas	**not GI**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
124	Airports	**not GI**	N/A	not GI	N/A	N/A	N/A	N/A	N/A	N/A	not GI
131	Mineral extraction sites	**partly GI**	not GI	not GI	partly GI	not GI	not GI	not GI	not GI	GI	not GI
132	Dump sites	**partly GI**	not GI	partly GI	not GI	not GI	not GI	not GI	not GI	GI	not GI
133	Construction sites	**not GI**	not GI	not GI	N/A	not GI	N/A	N/A	not GI	N/A	not GI
141	Green urban areas	**GI**	GI	GI	GI	GI	GI	GI	GI	N/A	GI
142	Sport and leisure facilities	**partly GI**	partly GI	not GI	partly GI	partly GI	GI	GI	not GI	not GI	GI
211	Non-irrigated arable land	**partly GI**	not GI	not GI	partly GI	not GI	not GI	not GI	not GI	GI	not GI
212	Permanently irrigated land	**partly GI**	N/A	partly GI	N/A	N/A	N/A	N/A	not GI	not GI	not GI
213	Rice fields	**GI**	N/A	GI	N/A	N/A	N/A	N/A	GI	GI	N/A
221	Vineyards	**partly GI**	not GI	partly GI	N/A	not GI	GI	GI	not GI	GI	GI
222	Fruit trees and berry plantations	**partly GI**	partly GI	GI	N/A	not GI	GI	GI	not GI	GI	GI
223	Olive groves	**GI**	N/A	N/A	N/A	N/A	N/A	N/A	GI	GI	N/A
231	Pastures	**GI**	GI	GI	GI	GI	GI	GI	GI	GI	GI

CLC code	CLC description	Transnational GI definition	Tri-Border Area (CZ, DE, PL)	Krkonoše Mountains National Park (CZ)	Karkonosze National Park (PL)	Kyjovsko (CZ)	Eastern Waldviertel & Western Weinviertel (AT)	Thayatal National Park (AT)	Upper Po Plain (IT)	Po Hills around Chieri (IT)	Dübener Heide Nature Park (DE)
241	Annual crops associated with permanent crops	**partly GI**	N/A	partly GI	N/A	N/A	N/A	N/A	N/A	N/A	GI
242	Complex cultivation patterns	**GI**	GI	GI	GI	GI	N/A	N/A	N/A	N/A	GI
243	Land principally occupied by agriculture, with significant areas of natural vegetation	**GI**	GI	GI	N/A	GI	GI	GI	GI	GI	GI
244	Agro-forestry areas	**GI**	N/A	GI	N/A	N/A	N/A	N/A	N/A	N/A	GI
311	Broad-leaved forest	**GI**	GI	GI	GI	GI	GI	GI	GI	GI	GI
312	Coniferous forest	**GI**	GI	GI	GI	GI	GI	GI	GI	GI	GI
313	Mixed forest	**GI**	GI	GI	GI	GI	GI	GI	GI	GI	GI
321	Natural grasslands	**GI**	GI	GI	GI	GI	GI	GI	N/A	N/A	GI
322	Moors and heathland	**GI**	GI	GI	GI	N/A	N/A	N/A	GI	GI	GI
323	Sclerophyllous vegetation	**GI**	N/A	GI	N/A	N/A	N/A	N/A	N/A	N/A	N/A
324	Transitional woodland-shrub	**GI**	GI	GI	GI	GI	GI	GI	GI	N/A	GI
331	Beaches, dunes, sands	**GI**	N/A	GI	N/A	N/A	N/A	N/A	GI	N/A	GI
332	Bare rocks	**GI**	GI	GI	GI	N/A	N/A	N/A	N/A	N/A	GI
333	Sparsely vegetated areas	**GI**	GI	GI	GI	N/A	GI	GI	GI	N/A	GI
334	Burnt areas	**GI**	N/A	GI	N/A	N/A	N/A	N/A	N/A	N/A	N/A
335	Glaciers and perpetual snow	**GI**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
411	Inland marshes	**GI**	GI	GI	N/A	GI	GI	GI	GI	N/A	GI
412	Peat bogs	**GI**	GI	GI	GI	N/A	N/A	N/A	GI	N/A	GI
421	Salt marshes	**GI**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
422	Salines	**GI**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	GI
423	Intertidal flats	**GI**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

CLC code	CLC description	Transnational GI definition	Tri-Border Area (CZ, DE, PL)	Krkonoše Mountains National Park (CZ)	Karkonosze National Park (PL)	Kyjovsko (CZ)	Eastern Waldviertel & Western Weinviertel (AT)	Thayatal National Park (AT)	Upper Po Plain (IT)	Po Hills around Chieri (IT)	Dübener Heide Nature Park (DE)
511	Water courses	**GI**	GI	GI	GI	GI	GI	GI	GI	GI	GI
512	Water bodies	**GI**	GI	GI	GI	GI	GI	GI	GI	GI	GI
521	Coastal lagoons	**GI**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
522	Estuaries	**GI**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
523	Sea and ocean	**GI**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

3.2 Data acquisition at transnational, regional and local level

As with any other mapping approach, high quality geodata regarding spatial and thematic resolution is an essential prerequisite to allow the operationalisation of the GI concept in the first place.

The requirement of incorporating green space elements on the state, regional, community and parcel scales (Benedict and McMahon 2002) emphasises the need for a profound data basis in terms of high spatial and thematic resolution geodata for local implementation of GI. For that reason, data acquisition at transnational, regional and local level is necessary in quite different ways, dependent on the scope and scale of GI implementation.

While the standardised CORINE Land Cover (CLC 2012) database was considered the most adequate (see Neubert and John 2019) for the mapping of GI on a transnational scale, there is no one-size-fits-all solution for the acquisition of suitable geodata at the regional and local level.

Therefore, the best solution to meet these requirements was the compilation of various regional geodata and small-scale field mapping data. Table 2 provides an overview of regional datasets used in the project case study areas for GI and BI mapping, ranging from e.g. regional land cover data to forest inventories and digital registration of GI elements from orthophotos.

The use of the highly detailed geodata set revealed differences in the realistic representation of the GI network in the different landscapes (Figure 4). On the one hand, due to the classification and generalisation inherent in CORINE Land Cover, the extent of fragmentation is distinctly under-represented in large continuous areas and small elements of GI, like woodlands or vineyards. On the other hand, apparently, e.g. arable land or urban fabric are often greatly underrated for their provision of GI and landscape features such as hedgerows, ditches, ponds and single trees. Therefore, the regional data set enhanced the evaluation of the GI network in natural and semi-natural areas as well as in rural and urban settings, which in the first place allows the regional operationalisation of the GI concept. The availability and thus comparability in most European countries is still a major benefit of the CORINE Land Cover classification, though.

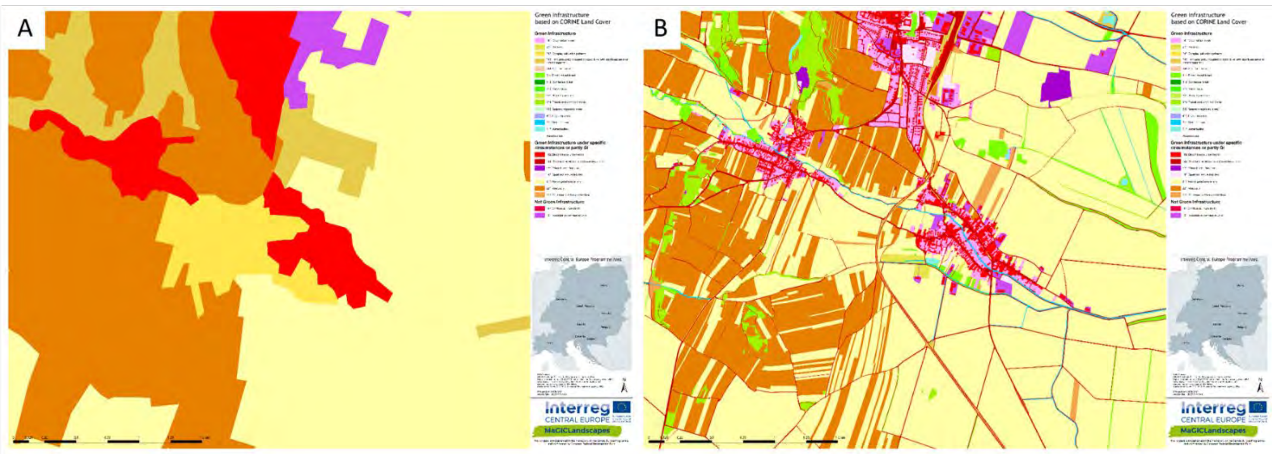

Figure 4: Example of GI elements based on CORINE Land Cover (A) and based on regional geodata (B) for the Austrian case study area "Eastern Waldviertel & Western Weinviertel".

Through the compilation of various forms of local data to produce a regional highly detailed geodata set, the mapping quality of GI can be enhanced for all types of landscapes and constitutes a precondition to develop stakeholder-based strategies and action plans for future actions and investment in GI. It also enables the precise identification of the local GI network for land managers, policy makers and communities.

Table 2: Datasets used for regional green and blue infrastructure mapping

Type of Dataset	Tri-Border Area (CZ,DE,PL)	Krkonoše Mountains National Park (CZ)	Karkonosze National Park (PL)	Kyjovsko (CZ)	Eastern Waldviertel & Western Weinviertel (AT)	Thayatal National Park (AT)	Upper Po Plain (IT)	Po Hills around Chieri (IT)	Dübener Heide Nature Park (DE)
Land cover	●			●			●	●	▫
Biotope mapping	●	●		●					●
Digital cadastre		●		●	●	●			
Agriculture				●	●	●			
Forestry		●		●	●	●	●	●	
Waterways	●				●	●	●	●	●
Geography and topography	●	●	●	●					
Orthophotos			●	●					

3.3 Generating transnational, regional and local maps of Green Infrastructure functionality

The assessment and mapping of GI functionality carried out in MaGICLandscapes comprised three main types of sub-analyses:

- the connectivity analysis (see 3.3.1)
- the field mapping methodology (see 3.3.2)
- the functionality analysis itself (see 3.3.3).

The methodologies were tested in all partner countries of the project: Austria, the Czech Republic, Germany, Italy and Poland. In this section we present each sub-analysis, divided into various steps, and provide examples of application in the case study areas.

3.3.1 Connectivity analysis

The analyses of connectivity were performed through the software GuidosToolbox (Graphical User Interface for the Description of image Objects and their Shapes). GuidosToolbox is a free software collection by Peter Vogt (Joint Research Centre (JRC) of the European Commission) and offers a variety of modules targeted to investigate several spatial aspects of raster image objects, for example pattern, connectivity, cost, fragmentation, etc.

The GuidosToolbox is freely available at: **https://forest.jrc.ec.europa.eu/en/activities/lpa/gtb/**.

Below, the three types of conducted connectivity analyses are explained.

3.3.1.1 Morphological Spatial Pattern Analysis

The Morphological Spatial Pattern Analysis (MSPA) is a generic and universal pattern analysis framework provided by a custom sequence of morphological operators (Soille and Vogt, 2009).

MSPA performs a segmentation on a binary image to identify and localise mutually exclusive morphometric feature classes describing the shape, connectivity and spatial arrangement of image objects by mapping and classifying them into categories (Vogt et al., 2017). The MSPA module automatically detects geometry and connectivity of the image components. Therefore, the foreground area of a raster based binary image is partitioned into seven MSPA classes: Core, Islet, Perforation, Edge, Loop, Bridge and Branch (Figure 5).

In order to perform the MSPA, an appropriate raster file has to be created as input data. In this case, this was done by dissolving and converting the used vector data in ArcGIS/QGIS and reclassify the pixel values (1 = GI or partly GI, 0 = not GI). Consequently, the resulting binary raster file contained all GI classes defined as such for each case study area. By selecting only single classes of GI, e.g. forests, grasslands or green urban areas, also a targeted evaluation of individual priorities could be performed.

In terms of the assessment of GI connectivity MSPA uses a series of image processing routines to identify hubs, links (corridors), and other features after reclassifying the raster land cover map into foreground (green infrastructure) and background (all other classes) (Vogt et al., 2007).

To align the terminology of green infrastructure, the category of core is equivalent to hub, and bridge is synonymous to link (corridor). First the MSPA processing identifies the category core, which is based on the connectivity rule used to define neighbours and the value used to define edge width (Soille and Vogt, 2009).

In the basic settings of MSPA, connectivity can be set to either four (cardinal directions only) or eight neighbours. The minimum size of core and the number of pixels classified as core is affected by the settings of the edge width. By increasing the edge width, the minimum size of core increases and thereby reduces the number of pixels defined as core areas. The decrease of core areas that results from increasing edge width create gains for all other classes, not just edge. This way increasing the edge width can shift core to islet if the area of core is small and core to bridge if the area of core is narrow (Wickham et. al. 2010).

In the application of MSPA in MaGICLandscapes we produced maps based both on the transnational and the regional dataset. We used eight-neighbour connectivity and an effective edge width value of 100 metres, at varying prerequisites regarding the pixel size of the input data, for the analysis on the transnational dataset. On the regional dataset, dealing with a pixel size up to 1 metre, the best results could be elaborated with an effective edge width value of ten 10 metres.

The input data are the raster (grid) maps of the green infrastructure maps of the case study areas. The input map must contain the two data classes: Foreground (GI) and Background (not GI). Therefore, the category “partly GI” has to be resolved and assigned unambiguously to the categories “GI” or “not GI”.

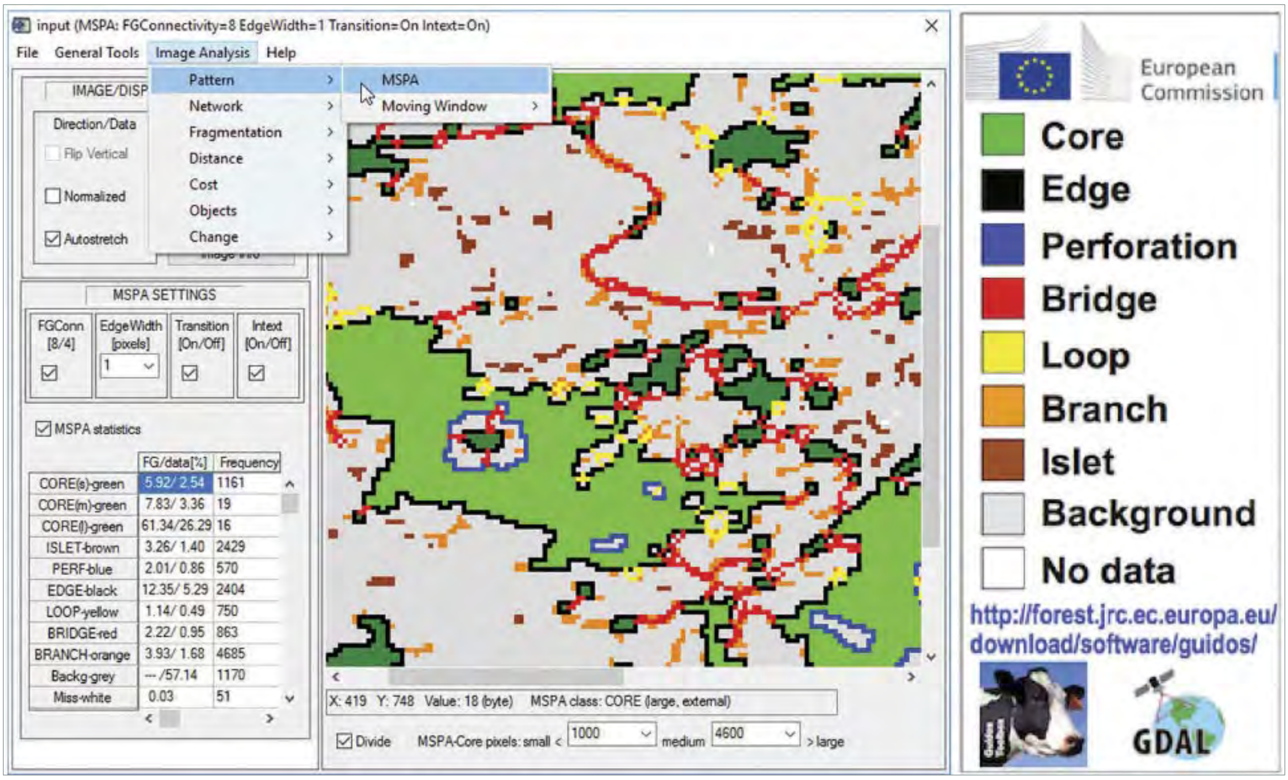

Figure 5: The GuidosToolbox software interface showing the MSPA pattern analysis illustrating various morphological feature classes: Small Core areas (dark green); large Core areas (green); Core area boundaries (Edge/external–black, Perforation/internal–blue); connecting pathways between different Core areas (Bridge–red) and returning back to the same Core area (Loop–yellow); isolated forest patches and too small to contain Core area (Islet–brown); and Branches (orange), reprinted from (Vogt et al., 2017).

Figure 6 shows the application of MSPA performed on the transnational dataset of the Austrian case study area *“Eastern Waldviertel & Western Weinviertel”* and *“Thayatal National Park”*.

Generally, a notable gradient in the distribution, proportion and formation of Core areas of GI (green) is visible. The degree of density and width of these connections and longitudinal extensions decrease from the west to the east, leading to some rather featureless landscapes in the eastern part. These agricultural landscapes show a lack of a GI network over large coherent areas of the Western Weinviertel, interspersed with island-like elements (e.g. woodlots and wind breaks). With certain exceptions of few large continuous woods, mixed formations of complex cultivation patterns consisting of vineyards, woodlots, pastures and agricultural land with significant areas of natural vegetation represent the class of Cores.

In the Western part there are larger coherent Cores, e.g. adjoining to the Thayatal National Park, and also significantly smaller Cores in the agricultural land between them. However, these are almost exclusively provided by coniferous forests interspersed with mixed forests to a small extent. The network of linear GI structures is also better developed, indicated by the higher amount of Bridges (red), Loops (yellow) and also Branches (orange).

The MSPA result can already provide an important insight on the different focal points of regional management plans. It also serves as the basis for the network analysis, described in Chapter 3.3.1.2.

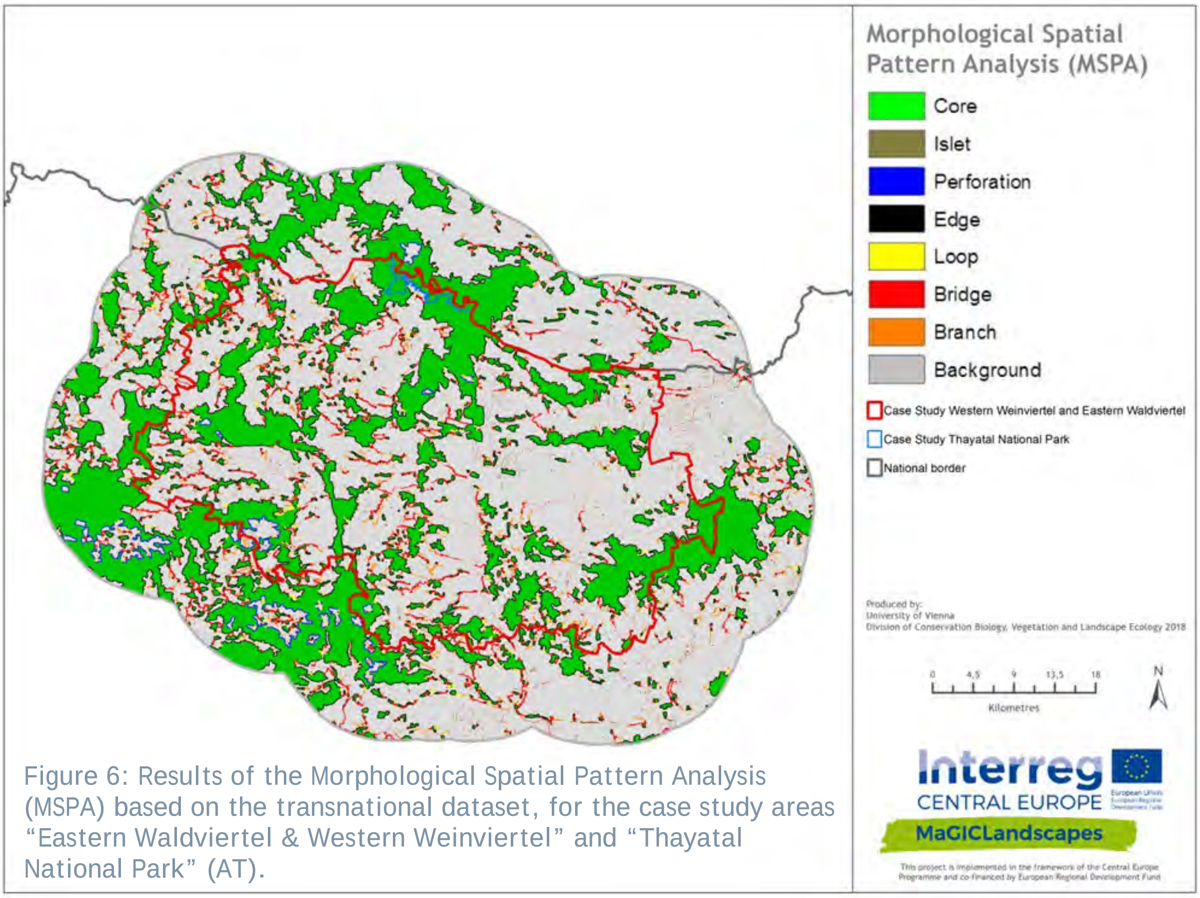

Figure 6: Results of the Morphological Spatial Pattern Analysis (MSPA) based on the transnational dataset, for the case study areas "Eastern Waldviertel & Western Weinviertel" and "Thayatal National Park" (AT).

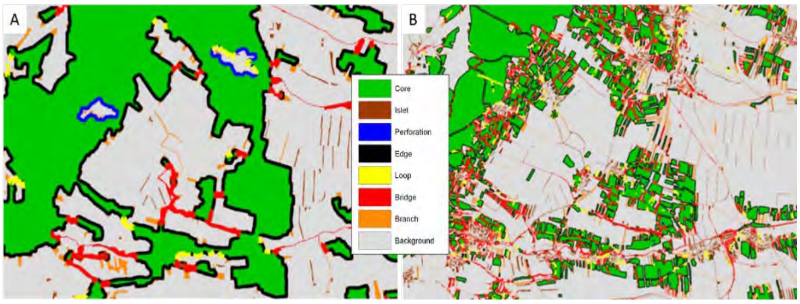

Figure 7: Exemplary detail section of the results of the Morphological Spatial Pattern Analysis (MSPA) based on CORINE Land Cover (A) and based on regional geodata (B) for the Austrian case study area "Eastern Waldviertel & Western Weinviertel".

Figure 8 shows the map of MSPA application with regional datasets for the Austrian case study area. Much more details become visible (compare Figure 7), highlighting fragmentation but also excessive branching of the GI network. What appeared to be large self-contained Core areas (green) of GI on the coarse scale – e.g. large continuous woods as well as mixed formations of complex cultivation patterns consisting of vineyards, woodlots, pastures and land principally occupied by agriculture, with significant areas of natural vegetation – are in fact partially highly fragmented cultural landscapes, represented by the presence of multiple and small Core areas (green) and the overarching classes of Bridges (red), Loops (yellow) and Branches (orange). Especially in the Western Weinviertel, the shapes of the Core areas, which appeared to be coherent on the transnational data, become significantly more fragmented at the regional data resolution.

Of course, the overall picture of the GI distribution remains unchanged, but the higher resolution of the structuring of GI provides an information that is crucial for smaller scaled, regional identification of areas of interest and therefore the implementation of GI management measures. It also emphasises the need for suitable geodata.

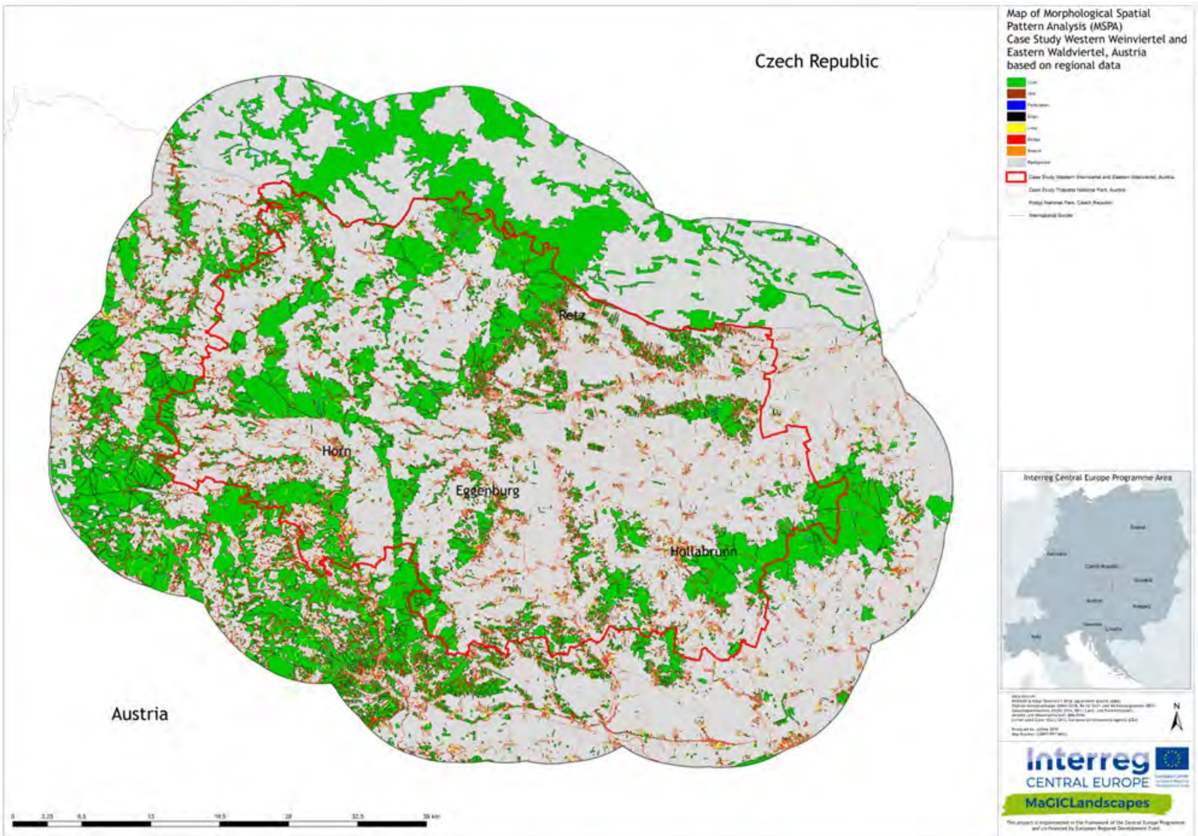

Figure 8: Results of the Morphological Spatial Pattern Analysis (MSPA) based on regional datasets, for the case study areas “Eastern Waldviertel & Western Weinviertel” and “Thayatal National Park” (AT).

3.3.1.2 Network analysis

Another informative feature of the GuidosToolbox is the automatic detection of connecting pathways between core areas of image objects based on the results of the initial application of MSPA.

In addition to the mere detection of connecting pathways the analysis, the module of NW Components/Node/Link Importance of GuidosToolbox ranks those detected pathways with respect to the relative importance of each component, node and link in a given network (Vogt et al., 2017) based on the application of the concepts and metrics of graph theory (Saura and Rubio, 2010; Saura, et. al, 2011).

In order to perform the network analysis, the result of the MSPA-analysis is used to create an image of the network of GI elements consisting of Nodes (MSPA class: Core) and Links (MSPA class: Bridge, respectively connectors between various Cores). All other MSPA classes, not contributing to the network are neglected. For further analysis of the network of green infrastructure in MaGICLandscapes’ case study areas we analysed the so-called NW Components and the Node/Link Importance:

Figure 9 shows the results of the Network Analysis based on the transnational dataset, for the same case study chosen for the Morphological Spatial Pattern Analysis. The Austrian case study areas show that interspersed mixed formations of complex cultivation patterns and woodland *“islands”* form the backbone (dark grey) of important Cores of the extended case study area. On the other hand, Links (highlighted in red) are mostly represented by streams, well equipped with adjacent structures of GI or buffer zones like riparian strips or woodlands and wet meadows. Moreover, linear corridors of complex formations of cultivation patterns mixed with dry grasslands represent very important Links in the case study area.

As the MSPA results already indicated, the Western part of the case study area contains of far more Cores and Links of high or at least medium importance than the Eastern part.

To conclude the most relevant connections are located as well as which Core areas are better interlinked and which are not. Thus, the priority areas of the existing GI and its corridors are determined.

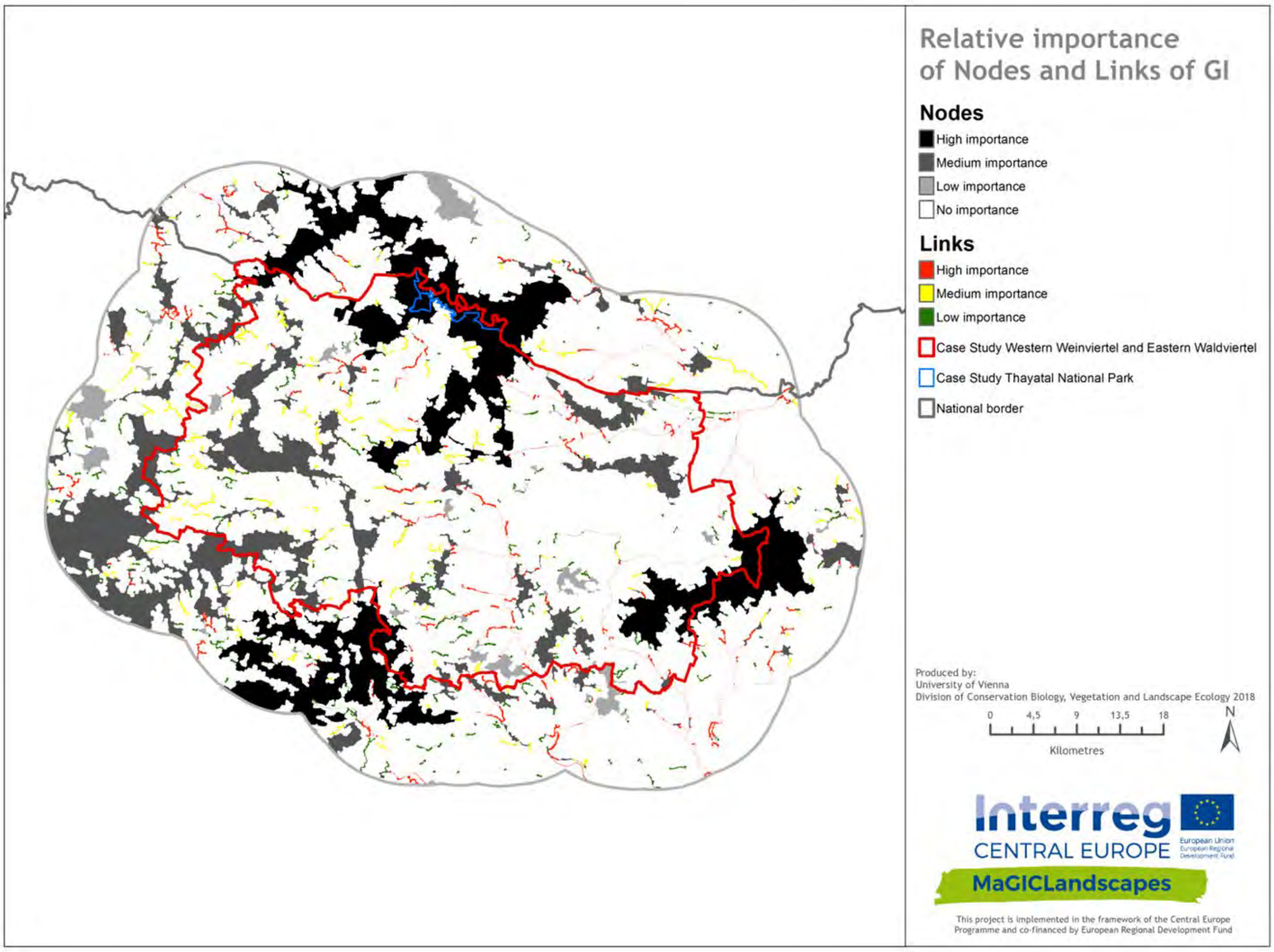

Figure 9: Results of the Network Analysis based on the transnational dataset, for the case study area "Eastern Waldviertel & Western Weinviertel" and "Thayatal National Park" (AT).

Due to the high resolution of the input data for the analysis of GI at regional and local level, the GuidosToolbox module Network analysis wasn't conducted at this spatial level.

3.3.1.3 Euclidean Distance

To measure the degree of intactness, shape and spatial arrangement of patches on a given binary map, which was also used for the MSPA, the analysis methodology of Euclidean Distance and Hypsometric Curve (HMC) offers a practical and effective method of implementation. The module of Euclidean Distance and HMC analysis scheme is also available in GuidosToolbox and uses the same input data as the MSPA described above.

This application creates maps of objects of interest showing the Euclidean distance map inside and outside those objects. To illustrate the influence zones of each object and to derive the pairwise proximity between neighbouring image objects this type of analysis may be further pursued. For the establishment of cost-efficient reconnecting pathways in restoration planning proximity may be used to locate close encounters of existing objects (Vogt et al., 2017).

In terms of the connectivity of green infrastructure the generated distance maps provide spatially explicit information allowing for highlighting hot spots of highly fragmented areas or those dominated by well-established networks of GI. The spatial information of these distance maps of GI may be of high importance for monitoring, planning and risk assessment.

Additionally, the simple, yet intuitive analysis scheme is easy to communicate and can be related to a variety of spatial planning measures by illustrating the degree of fragmentation or intactness and allowing direct comparisons with results among the case study areas.

The Euclidean Distance was applied both on the transnational dataset and on the regional datasets and shows the results based on the transnational dataset, for the Austrian case study (Figure 10) that was already described for the Morphological Spatial Pattern Analysis and Network Analysis and for another example of the Czech case study area Kyjovsko (Figure 11).

For the case study area in Figure 10, the results of the analysis support the outcome and the interpretation of the previous MSPA and Network Analysis. The measurement of Euclidean Distance provides information on the influence zones of elements of GI: the produced actual and potential connecting elements are represented by the water course network. In many places these channelled, straightened and deepened streams are in direct contact with the adjoining arable land and are characterised by the total absence of adjacent structures of GI or buffer zones like riparian strips or woodlands and wet meadows. Also, the hot spots of GI can be identified.

Despite the often reduced buffer zones along the water courses, the results underpin the importance of these water network as an element of GI and the need to promote buffer zones for the preservation of functional connectivity.

In the somewhat featureless landscapes of the agricultural environment in the east of the case study area the small-scale network of shelter belts and wind breaks was particularly highlighted by the illustration of the Euclidean Distance giving an indication of the importance of current elements and of the need for further establishment of such a network in the intensively used areas.

The already well-established network of GI represented by mixed formations of complex cultivation patterns consisting of vineyards, woodlots, pastures and land principally occupied by agriculture was underscored by the analysis. Additional cross-linking possibilities of these complex landscape patterns contributed considerably to the highlighted potential connecting pathways.

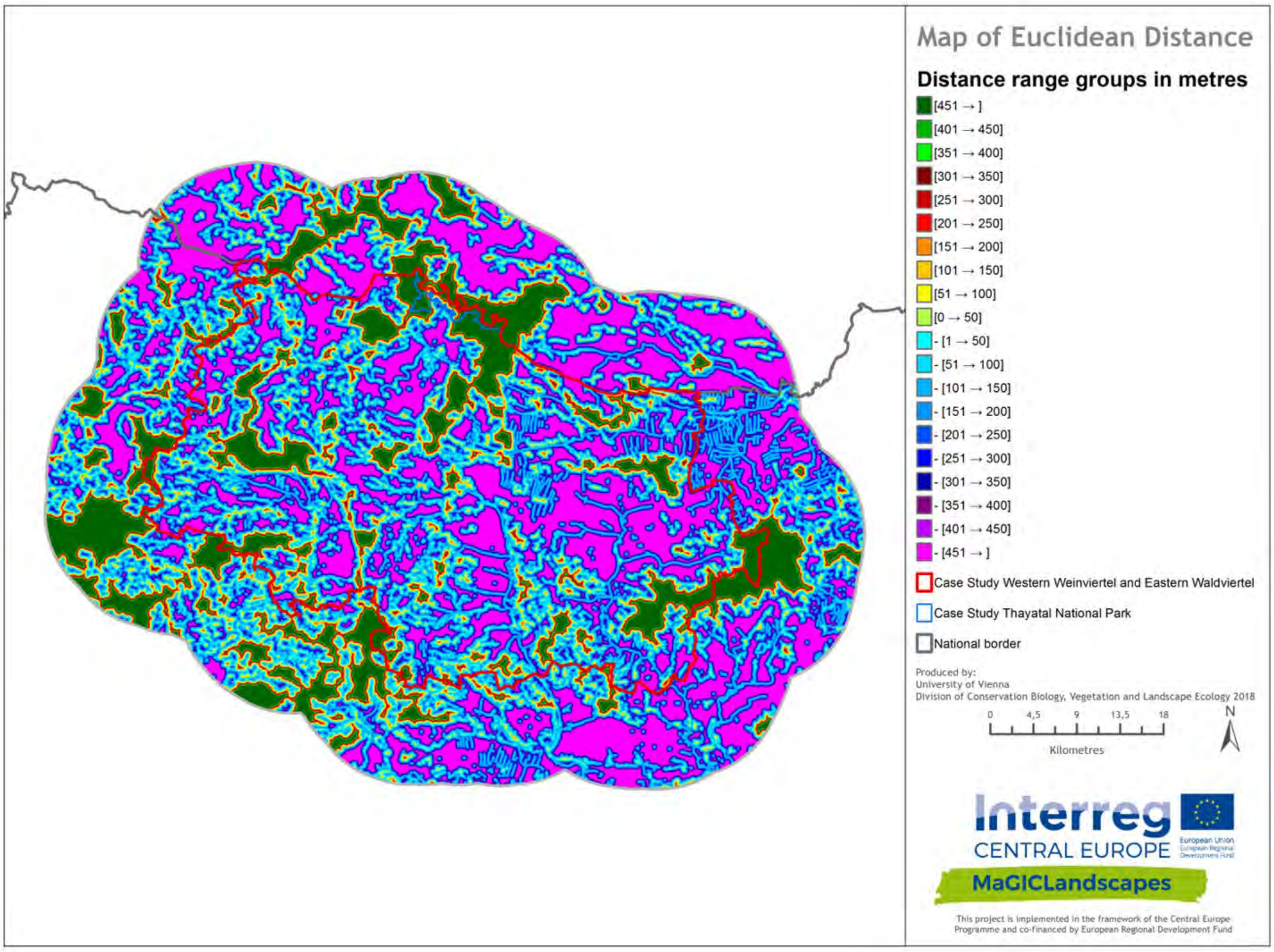

Figure 10: Results of the Euclidean Distance based on the transnational dataset for the case study areas “Eastern Waldviertel & Western Weinviertel” and “Thayatal National Park” (AT).

In the Czech case study area Kyjovsko the Euclidean Distance analysis (Figure 11) highlighted missing GI elements even more than the previous two analyses. It did confirm the lack of GI in the north and southeast of the wider area of the Kyjovsko region as well as in the southern half of the case study itself. It also showed potential for strengthening GI along the corridors/links, especially those formed by rivers that, as well, are usually accompanied by very narrow strips of woody or grassland vegetation but also patches of complex cultivation patterns that could provide many ecosystem services.

The second example, too, emphasises the role of the mostly small-scale GI functioning as corridors within the intensively used landscape between the Core areas of GI. As it can be seen in the map below, they represent an essential part of the GI network, despite their low lateral extent.

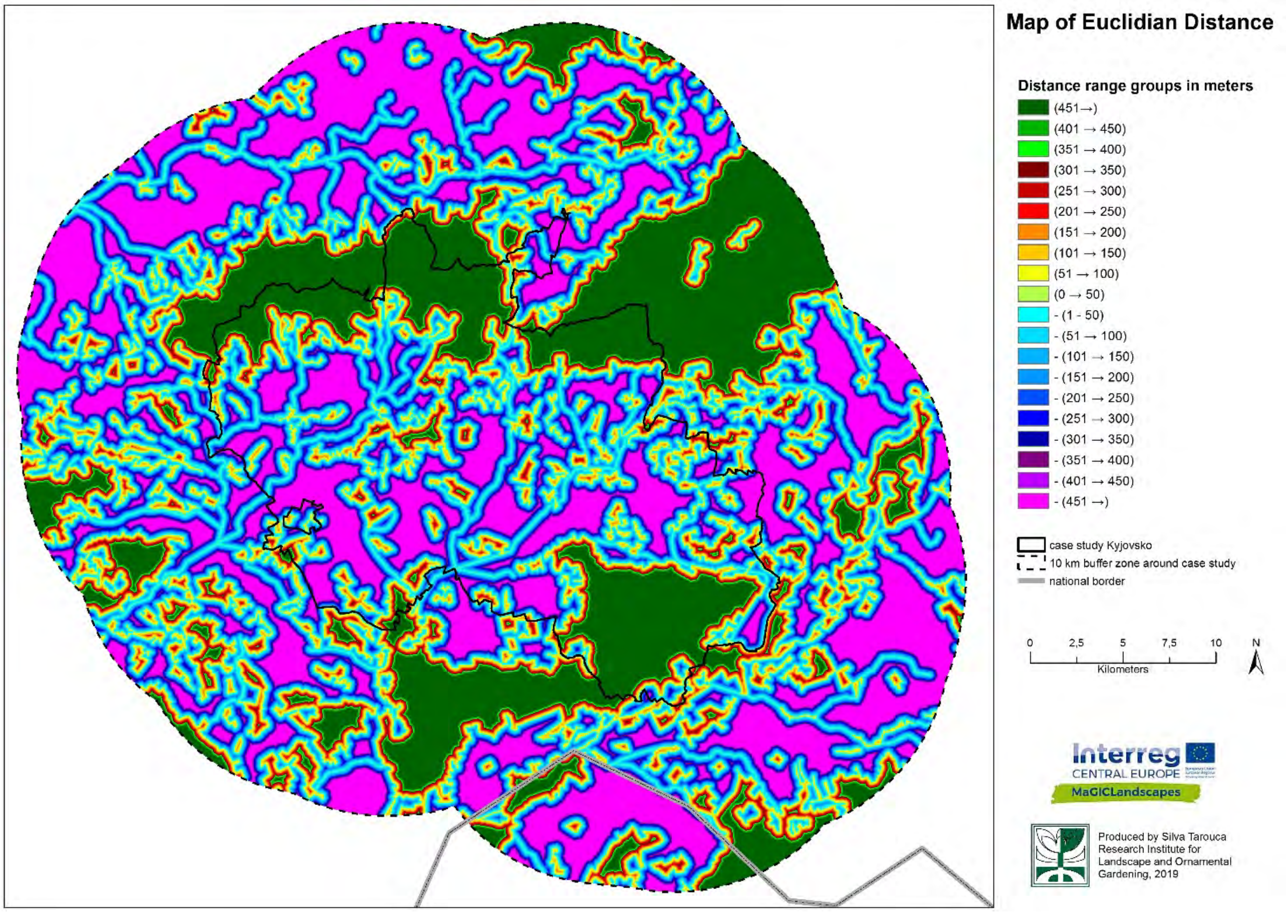

Figure 11: Results of the Euclidean Distance based on the transnational dataset for the case study area Kyjovsko (CZ).

Figure 12 shows the results from the regional and local implementation of Euclidean Distance for the Austrian case study areas. It demonstrates a much more detailed picture on the influence zones of GI elements. Due to the inclusion of further small GI elements like rivulets, embankments, roadside greenery, house gardens and green spaces the cross-linking possibilities within the case study area come fully to attention. On the other hand, comprehensive non-fragmented elements seem to be highly influenced by fragmentation through the presence of an exhaustive transport network or interspersed areas of intensively used arable land.

By using the regional data, the hot spots and the fine GI networks as well as the cold spots and fragmenting structures are shown far more realistically in comparison with the results from the CORINE data (Figure 13). It provides an excellent map for finding crucial GI structures and address their intactness and connectedness.

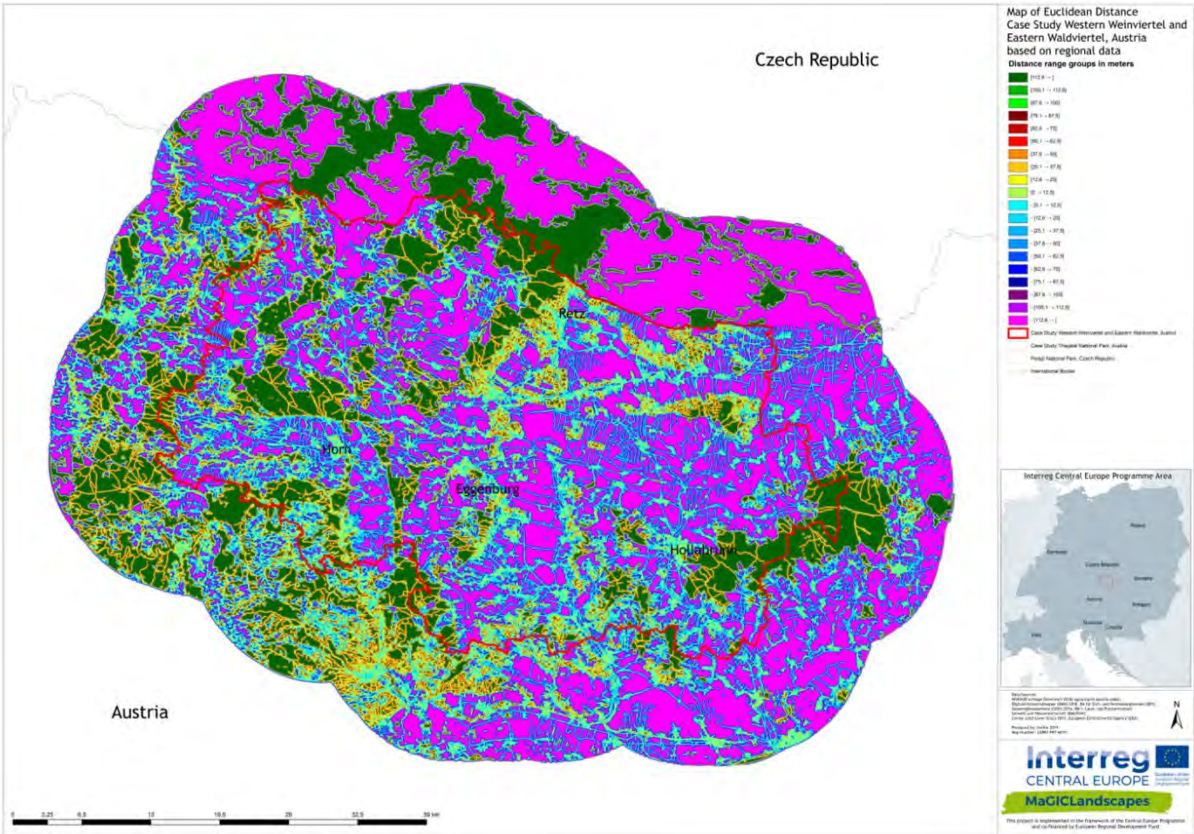

Figure 12: Results of the Euclidean Distance based on the regional datasets for the case study areas “Eastern Waldviertel & Western Weinviertel” and “Thayatal National Park” (AT).

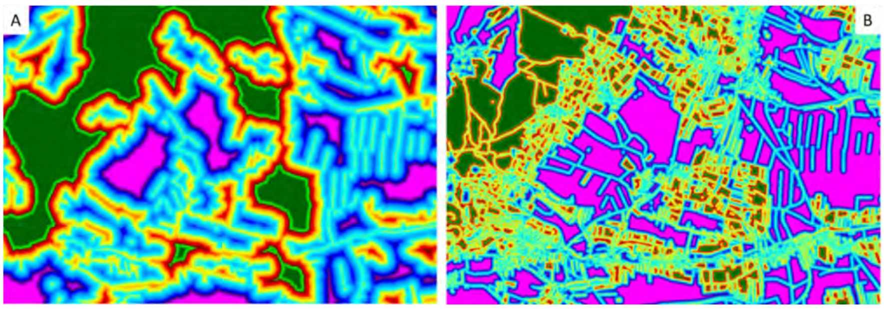

Figure 13: Exemplary detail section of the results of the Euclidean Distance based on CORINE Land Cover (A) and based on regional geodata (B) for the Austrian case study area “Eastern Waldviertel & Western Weinviertel”.and based on regional geodata (B) for the Austrian case study area “Eastern Waldviertel & Western Weinviertel”.

The map of the case study in Kyjovsko with Euclidian distances based on regional and local data also further underlines fragmentation of forest cores in north and southeast by forest roads. This is true especially for Kyjovsko where more detailed data was available. Meanwhile in the surrounding municipalities where only the consolidated layer of ecosystems, which includes only paved roads, was available, the same type of forest cores appears more or less intact.

In Figure 14 and Figure 15, these striking differences between the different data sources can be clearly seen: on the one hand, smaller influencing zones, on the other hand more connections (displayed in yellow and blue) and stronger influence of cores (displayed in green and red), which is particularly attributed to small holdings, woodlots but also to vineyards and orchards, especially in cases where they are accompanied by woody and grassland strips.

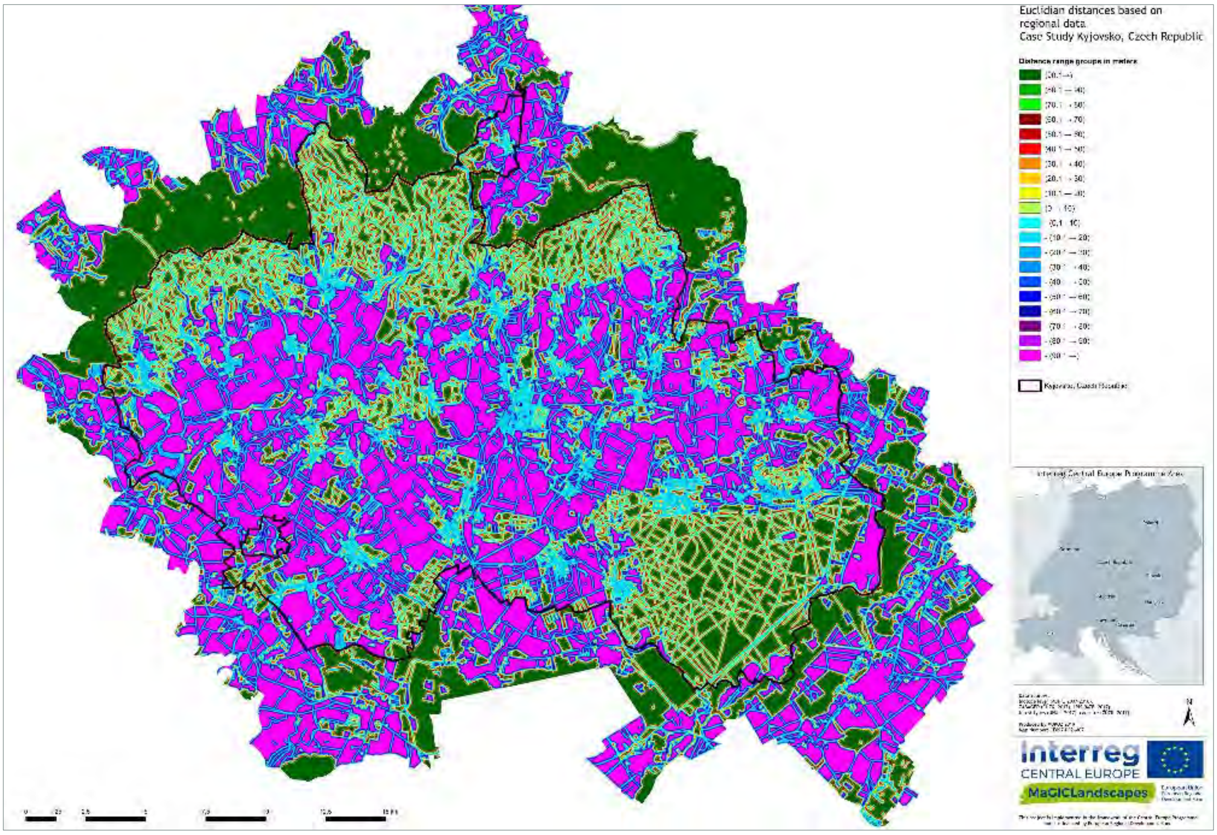

Figure 14: Results of the Euclidean Distance based on the regional datasets for the case study area Kyjovsko (CZ).

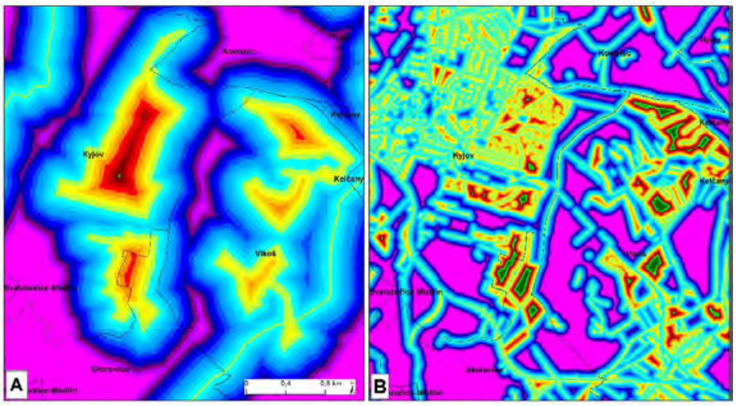

Figure 15: Exemplary detail section of the results of the Euclidean Distance based on CORINE Land Cover (A) and based on regional geodata (B) for the Czech case study area “Kyjovsko”.

3.3.1.4 Feedback on the connectivity analysis

Based on the partners' experience in the assessment of the MSPA in GuidosToolbox and the critical analysis of the results, the methodology appears useful and valid. The modules of GuidosToolbox are easy to use and the freely accessible nature of the software greatly facilitates the use beyond this application in MaGICLandscapes. Although the results are easily transferable into GIS applications, some problems exist with the creation of legends for respective maps, which have to be usually manually adjusted and that is time consuming. The MSPA analysis is quite self-explanatory. If very detailed spatial data is used, GuidosToolbox provides very useful results for GI and landscape planning and management, especially when the results are compared with other methods and analysis. Secondly, the results of GuidosToolbox analysis can be used further for spatial planning analysis and strategic documents. In general, the combination of the resulting maps allows getting an idea about functionality of the selected landscape resp. GI elements. The only limitations in the usability of the software seem the availability of input data and the size of the case study areas to compute.

The interpretation of maps of Euclidean distances is a bit more complicated but can be rather easily explained when following a set of rules – 'pink' colours show spaces that lack any GI and therefore are the target for GI implementation. 'Green and red' colours show very good GI presence, while 'yellow and blue' colours show presence of GI that could be improved.

Due to the resolution of spatial data available from the transnational application the results of the three analysis procedures provide fundamental insights and allow the development of transnational and supra-regional concepts dealing with GI. The intuitive analysis schemes of MSPA and Euclidean Distance can be related to further spatial planning measures and are also easy to communicate.

As mentioned above, due to the high resolution of the input data for the analysis of GI at regional and local level, the GuidosToolbox module Network analysis wasn't conducted at this spatial level. In addition, the underlying theory and background of the analysis, i.e. about graph theory, are not this easily comprehensible and self-explanatory as the modules of MSPA and Euclidean Distance.

The analyses performed show two approaches using different datasets. The transnational approach is based on CLC data (outdated, with low resolution and with subjective errors in class interpretation), using a pre-set edge width of 100 m. This might be good for transnational/national analyses but for local and even regional analyses more detailed data and finer criteria should be used. This is clear from the second approach, which used regional and local data, applying finer resolution (up to 1 m sized pixel) and also finer criteria (edge width of 10 m). This approach reveals not only 'hidden' connecting GI elements and cores but also the larger fragmentation of presumably undisturbed GI elements.

Another point is the fact that by clipping data, i.e. creating an 'island', the results might be a bit different, especially at the edges of this 'island' than when using (spatially) wider datasets. For this reason, a buffer area of 10 km was placed around the case study areas to reduce boundary effects. This fact is relevant especially in case of using Network Analysis. For the overview of the situation, however, this kind of analysis is quite illustrative.

3.3.2 Field mapping methodology

The key tool for the assessment of green infrastructure at the local level was the on-site inspection of selected test sections within the case study areas. The selection was derived from the results of the map of green infrastructure based on CORINE (2012) as well as the Morphological Spatial Pattern Analysis (MSPA) and the measurement of the Euclidean Distance in order to locate GI that is important for the connectivity on the landscape scale. The aim of the local GI mapping was to deliver a detailed view of the selected sites that shows the high diversity actually hiding behind the more general classes of CORINE or even the regional datasets. The data was then further processed using GIS software (ArcGIS, QGIS) and Microsoft Excel.

3.3.2.1 Field mapping

In the course of the GI mapping, areas of sufficient size have been chosen in advance. The test sections of the GI assessment should be located in areas of special interest or sites of potential intervention such as core areas, corridors, nodes, stepping stone, etc. or ecologically sensitive areas. The chosen area size and shape can be adapted to the MSPA classes (e.g. core vs. bridge). However, the cumulative area of the sites should be (at least) 1 km^2.

On-site, with the aid of the EUNIS (European Nature Information System) habitats classification (level 3) (Davies & Moss 1999; Davies et al., 2004) and the corresponding national biotope types as well as the Mapping guidelines developed within the project MaGICLandscapes, the habitat types of homogenous units of landscape elements were determined by using indicator species and habitat descriptions of the EUNIS catalogue. The EUNIS habitat classification is *“a comprehensive pan-European system to facilitate the harmonised description and collection of data across Europe through the use of criteria for habitat identification. The classification is hierarchical and covers all types of habitats from natural to artificial, from terrestrial to freshwater and marine”* (EEA - European Environment Agency 2014).

In the meantime, however, an official translation document between CORINE Land Cover and EUNIS (European Environment Agency, 2009) as well as various national and international biotope classification schemes are in place and constitute a helpful aid for the implementation of field mapping.

Subsequently, each GI element was cartographically demarcated on aerial images of the study area. The hemerobiotic state or the level of naturalness was classified according to Sukopp (1969) and Walz et al. (2014) on a scale from 1 (metahemerobic or artificial) to 7 (ahemerobic or natural) using not only several indicative examples for e.g. agricultural land, but also requiring expert interpretation of the specific landscape structure and biotope features in the study areas. At last, general characteristics and barriers, that reduce the permeability of GI, were noted in the provided field mapping form.

3.3.2.2 Data visualization

Subsequent to the field work a geodatabase was built up by joining the spatial information of the GI elements with the according obtained field work data. Thus, various maps can be created which depict high-resolution images of the present situation.

Comparing GI on transnational, regional and local scale

One important result of this assessment is to show the advantage of the local GI assessment in terms of spatial and qualitative resolution. In contrast to the previously compiled maps of GI using transnational CORINE (2012) data only on the one hand, and the refined map of GI considering several, more accurate national sources of data (e.g. water network or cadastral map) on the other hand, a much more detailed view of the functional and qualitative diversity as well as the connectedness of GI can be achieved with the local assessment. In addition, the categories of the EUNIS habitat classification (2017) provide a characterisation of GI that is comparable at the international level. The following pages exemplary demonstrate the local GI assessment in the case study areas Eastern Waldviertel & Western Weinviertel (AT) and Dübener Heide Nature Park (DE).

Eastern Waldviertel & Western Weinviertel (AT)

The GI assessment in the Austrian case study area (Figure 16) was focused on wetland habitats and waters. The mapping was conducted in a quadrant of 0.4 square kilometres (400 x 1000 m).

It can be noted, that the transnational map of CORINE Land Cover (CLC) lacks many details, especially in regard to small water bodies and associated vegetation. Several tracks between a smaller structured agricultural landscape as well as many green urban areas, such as gardens, can be identified at the regional and particularly at the local level. Overall, a remarkable increase in the number of land cover/biotope classes can be seen. Whereas the regional CLC map contains 15 categories, the local assessment revealed 39 EUNIS categories.

Another striking difference revealed by the field mapping, but also already on the regional level, is the course of the River Pulkau and its associated habitats in this quadrant. The natural course of the river in the municipality Zellerndorf could be partly restored. As seen in the map (Figure 16c), there are several wetland habitat types, such as species-rich helophyte beds, water-fringing reed beds or riparian woodland along the river. On sites with dryer conditions, xeric types of grassland could be identified.

Figure 16: Map of green infrastructure based on CORINE Land Cover (2012) at transnational (a) and regional (b) resolution compared to GI based on the EUNIS habitat classification (2017) on the local scale with the focus on wetland habitats and water (case study area Eastern Waldviertel & Western Weinviertel, AT).

Dübener Heide Nature Park (DE)

The results for the evaluation of GI in the urban periphery of the city of Eilenburg can be seen in Figure 17. Eilenburg lies on the edge of the Dübener Heide and belongs to the extended research area. The diversity of habitat types is reflected in the sheer number of habitat classes. On a transnational level there are only 4 CLC classes. On the basis of the regional data 14. And in the course of the mapping 22 EUNIS classes were determined in the quadrant. The River Mulde forms the main axis of green infrastructure in the urban area of the city of Eilenburg. Alluvial vegetation, grassland and large and old trees form the accompanying vegetation of the river. The local mapping (Figure 17c) shows a structurally very rich landscape, where unmanaged mesic grassland, low and medium altitude hay meadows, riverine scrub, agriculturally-improved, re-seeded and heavily fertilised grassland and early-stage natural and semi-natural woodlands and regrowth alternate with parkland. There are also urban uses such as sports fields, an event area and residential buildings of villages and urban peripheries. Barriers and obstacles to the network and the connections of green infrastructure can also be seen. Road and railway networks are easy to recognize. Individual green elements within the urban and industrial areas as well as parks, allotments, and green areas can be identified. Tree rows and roadside greenery occur only to a limited extent, since the registration of such small-scale structures is very complex.

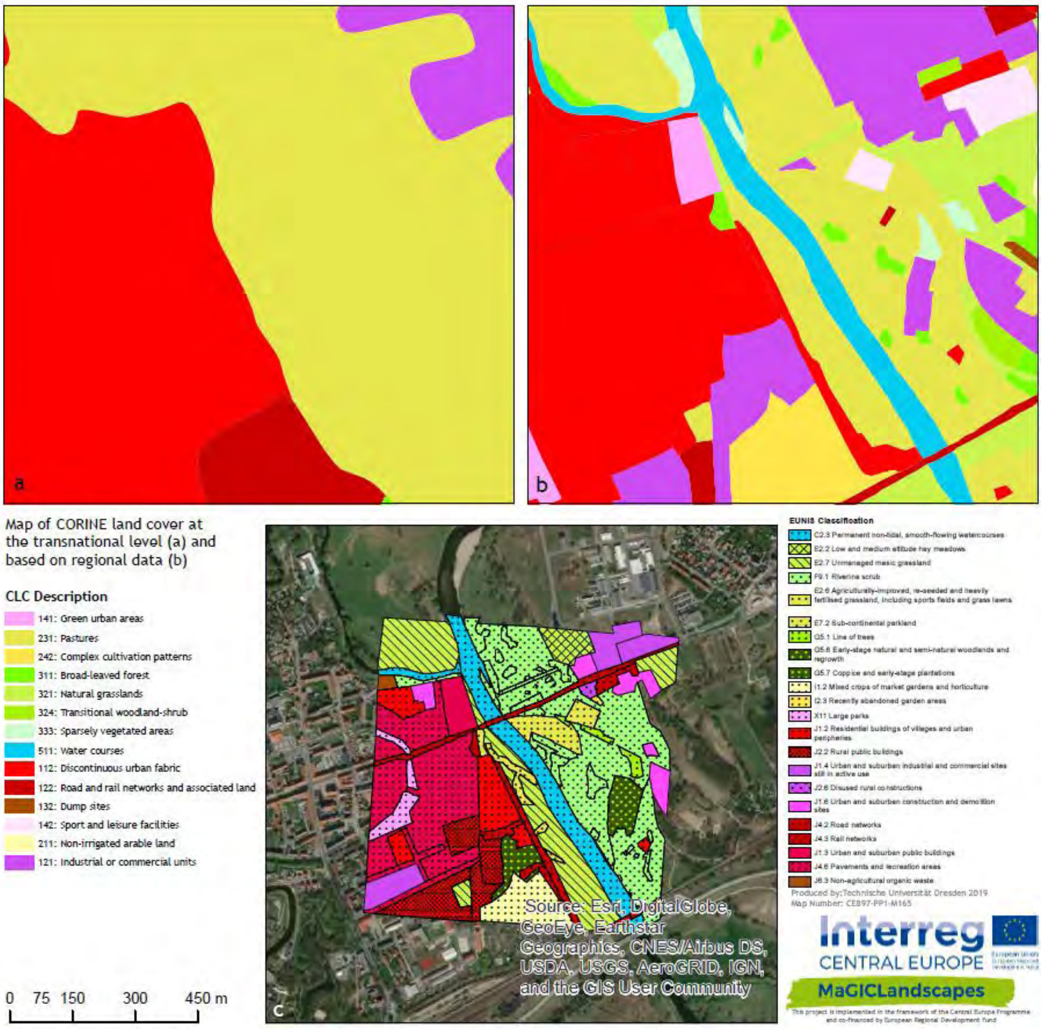

Figure 17: Map of green infrastructure based on CORINE Land Cover (2012) on transnational (a) and regional (b) resolution compared to GI based on the EUNIS habitat classification (2017) on the local scale (c) with the focus on the urban periphery in the city of Eilenburg (Dübener Heide case study area, DE).

Level of naturalness

The other main output is an equally detailed view of anthropogenic influence on the elements of GI. These maps of the state of naturalness serve as basis to determine local high priority areas where the need for action to improve or maintain GI is given.

The hemeroby index measures the hemerobiotic state of an area: the magnitude of the deviation from the potential natural vegetation caused by human activities.

Gradients of human influence are assessed using a scale which normally comprises 7 degrees, in which the highest level (ahemerobic) correspond to *"natural"* or non-disturbed landscapes and habitats such as bogs and the lowest level (metahemerobic) are given to totally disturbed or *"artificial"* landscapes such as urban areas. In an agri-environmental context the index shows the cultural influence of farming practices on landscapes and potential vegetation.

The assignment of a land use class to a special degree of hemeroby respects the intensity, duration and range of human impact (Sukopp 1969). While for example residential areas are characterised by a high degree of soil sealing, which has a high impact on ecological function, and is mostly of long duration, agricultural and forestry areas contain different intensities of use (Walz et al. 2014).

According to the Joint Research Centre of the European Commission and their scientific and technical report *"Implementation of an EU wide indicator for the rural-agrarian landscape"* (Paracchini et al. 2011) hemeroby or rather the degree of naturalness was found to be one of three proposed indicators besides structure and societal awareness of rural landscapes.

The assessment gives an interesting insight in the quality of GI. Generally, the high value of GI functioning as corridors within the cultural landscape, like rivers and their accompanying woodland as well as other (semi-)natural areas like woodland and more extensively used grasslands, is highlighted. These elements are essential in the matrix of agricultural used land that is at least rated as far from natural (3). In contrast to the GI with high level of naturalness, artificial structures or intensively used land show a very low degree of naturalness respectively a high degree of hemeroby.

Table 3: Table of hemerobiotic state respectively level of naturalness according to Sukopp (1969) and Walz et al. (2014)

Level of naturalness		Hemerobiotic state	Definition	Processes/Human impact	Indicative examples
1	Artificial	Metahemerobic	paved, built up, destroyed	Sealed surface, biocenosis destroyed	streets buildings sealed surfaces concreted channels and waters landfills mining lands
2	Strange to natural	Polyhemerobic	completely transformed	Strong changes in biocenosis, covering of the biotope with external material	non-native forests without undergrowth intensive vineyards and orchards with tillage

					poorly-structured house gardens weed-free farmland extremely species-poor intensive cultivated grassland canalised waters solar fields wind parks city green golf courses pits/open cut mines
3	Far from natural	a-euhemerobic	partly transformed	Substitution of natural with alien vegetation; deep ploughing, planting, major changes in matter circle, drainage, heavy use of fertilizers and biocides	poorly-structured forests forest dominated by alien species farmland with site-specific weeds species-poor fertilized meadows and pastures grassed vineyards and orchards short-term fallow land spontaneous vegetation richly-structured house gardens embanked waters
4	Relatively far from natural	b-euhemerobic	strongly influenced	Major modification of forest natural composition; use of fertilisers and biocides melioration, ditch drainage	richly-structured forests forest dominated by species atypical for the site or with high presence of alien species species-rich slightly fertilized meadows and pastures extensive vineyards mid-term fallow land annual crops associated with permanent crops (extensive) extensive arable land olive groves with permanent vegetation cover

					agroforestry intensive grassland partly embanked waters, potential occurrence of vegetation or fish
5	Semi-natural	Mesohemerobic	moderately influenced	Moderate modification of forest composition, clearing and occasional ploughing, extensive grazing, infrequent and small doses of fertiliser	multi-storied intermediate managed forests with high percentage of deadwood forests with low species diversity and increasing presence of atypical species extensive meadows and pastures long-term fallow land highly diversified agroforestry systems (wood pasture, grazed woodlands) waters with natural bank and streambeds surrounded by cultivated land, managed forest or sporadic water control structures
6	Close to natural	Oligohemerobic	seminatural	Limited removal of wood, pastoralism, minor changes in matter circles, pollution through air and water	close to nature managed forests forests with species typical for the site and diverse near-natural biotopes semi-natural grasslands primary and secondary dry grasslands stages of succession close to climax
7	Natural	Ahemerobic	Natural	No disturbance	intact bogs pristine forests or waters no utilisation

As shown in Figure 18, the results represent this pattern of qualitative patches and fragmenting anthropogenic structures very well.

The assessment of the study area along the River Pulkau (Figure 18A) depicts the anthropogenic highly modified and destroyed areas, such as buildings, roads or agricultural waste deposits. On the other hand, there is the river with its immediate vegetation and the various types of grassland are natural and semi-natural, respectively. Noteworthy is also the difference between the managed river sections within and outside of the restoration area.

The analysis of the naturalness in the urban area of the city of Eilenburg along the River Mulde is shown in Figure 18B. It shows that the urban and sealed areas are clearly marked with index 1 and 2. Also roads and railway lines. Parks, allotments and ruderal areas were classified as Level 3 (far from natural). To the north of the study area is a nature reserve on an island in the middle of the Mulde. This was evaluated with index 5 (semi-natural). The GI along the Mulde was rated Level 3 or 4.

So, while the classification of the EUNIS categories tells the mapper what GI elements are in the study area, the evaluation of the naturalness gives clear information about the ecological quality of those elements. This is very useful to distinguish within the elements categorised as *GI* or *partly GI* and of course *not GI* in terms of their condition. This allows the determination of the high-value areas on the local scale and, subsequently, appropriate recommendations for managing can be given and actions be taken to maintain or improve the situation.

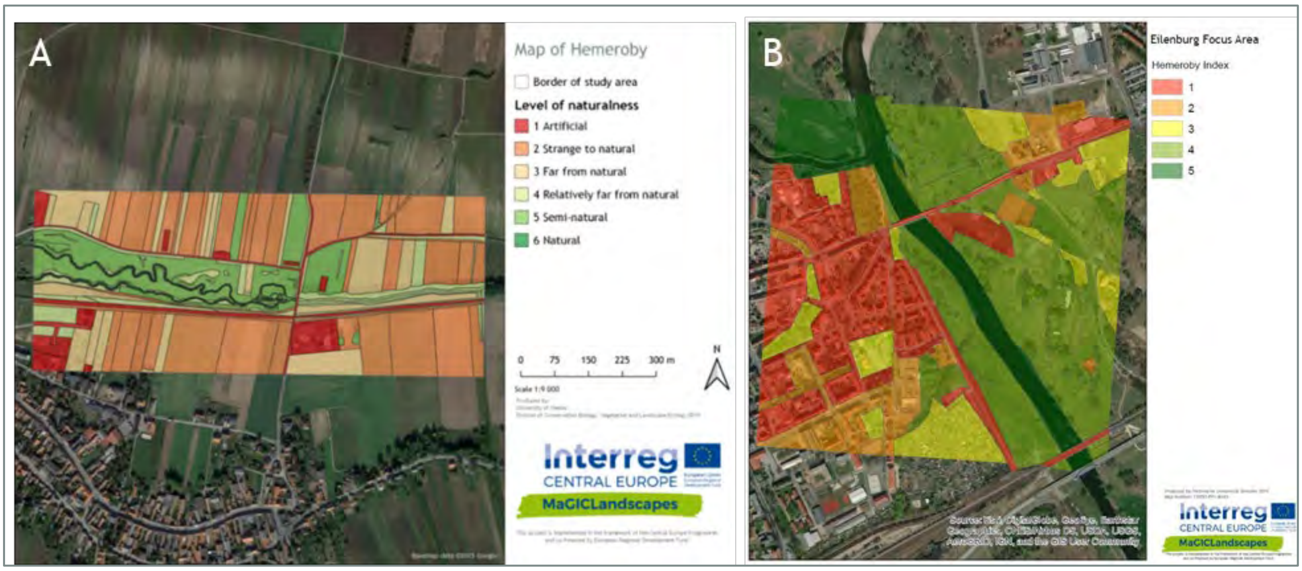

Figure 18: Results of the local GI assessment, showing the level of hemeroby, for the case study areas Eastern Waldviertel & Western Weinviertel (A) and Dübener Heide Nature Park (B).

Barriers

Aside from the EUNIS habitat map, which already delivers an accurate picture of the GI network on the local scale, taking barriers (walls, fences or other structures) within the single GI elements into account improves the view on the connectivity of GI in the case study areas even further.

In the context of GI, barriers reduce the permeability of GI to fauna and flora (and people). Lack of movement possibilities affects the gene flow of the population and may lead to local extinction. Anthropogenic structures, like buildings or fenced gardens mostly have a barrier effect within the landscape. However, the hemeroby does not always indicate the presence of barriers in the element.

This allows the detection of areas with limited permeability in order to develop specific management strategies at a regional and local level to manage existing or implement potential GI and to remove obstructions and barriers where possible, in order to create the possibility of ecological corridors for species migrations and genetic exchange.

Within the assessed quadrant of the Austrian case study area (Figure 19A) are a few elements with obvious barriers like discontinuous urban areas, industrial sites or gardens. Also the rail tracks by the River Pulkau have a barrier effect. But the largest barrier in this sample area is the fenced grassland of the restoration area, where grazing is used as a management method.

The assessed quadrant of the case study area Krkonoše National Park (CZ) surrounding the mountain villages and towns is shown in Figure 19B. There the enclosure of estates and plots by railings and walls is predominantly not allowed due to nature conservation, but it is possible to identify the land use/habitat categories with high barrier effect in each case study area. As expected, the buildings and main roads in particular have a high barrier effect. Sport and leisure time facilities during the main tourist seasons (roads, trails, ski-lifts, ski-slopes etc.) play a very important role. A high barrier effect was detected in the continuous build-up area in the centre of the village and by those main roads with high traffic intensity.

Figure 19: Results of the local GI assessment showing the barriers for the case study areas Eastern Waldviertel & Western Weinviertel and (A) and Krkonoše National Park (B)

3.3.3 Functionality analysis

3.3.3.1 Preparation of landscape service capacity matrix

The analyses of functionality were performed by plotting capacities of GI elements and all other land use classes to provide landscape services on the above mentioned rationalized geodata stets. Especially when based on participatory approaches, capacity matrices are widely used for assessment of ecosystems services (ESS), perfectly corresponding to MaGICLandscapes' motivation and objectives.

Basically, a capacity matrix is a look-up table that connect land cover types to ecosystem services or landscape services potentially provided. Introduced by Burkhard et al. in 2009 the method has since been developed and applied in an array of case studies (Campagne et al. 2017).

To create a sound matrix of landscape services capacities for the CORINE Land Cover types in central Europe, an existing matrix for the whole of Europe by Stoll et al. (2015) was used. It was assigned to the definitions of landscape services by de Groot et al. (2002, 2006 and 2010) and revised by the experts of each project partner. The key tool for the analysis of GI functionality was the resulting final matrix of landscape services, consisting of 30 single ESS in five main services that are aggregated to the total function value for each land cover type.

By the definition of the Millennium Ecosystem Assessment (MEA) *"ecosystem services"* comprise various benefits for the people provided by ecosystems. They can be divided into four categories:

- Provision services (e.g. food, fresh water)
- Regulating services (e.g. climate regulation, pollination)
- Cultural services (e.g. recreation, education)
- Supporting services (e.g. soil formation, photosynthesis)

Thus, these ecosystem services not only sustain fundamental human needs but also have a high economic value (MEA, 2005; TEEB, 2010). In order to understand and quantify these complex socio-ecological systems and develop models of ecosystem services, assessment matrices are a common tool in this research field (Burkhard et al., 2009, 2012; Stoll et al., 2015).

As mentioned above, for the evaluation methodology of the current project, the matrix of Stoll et al. (2015) was used as basis for discussion. Compared to the concept of landscape services by de Groot et al. (2002, 2006 and 2010), it uses four ecosystem services groups (Ecological integrity, Regulating services, Provisioning services and Cultural services) comprising 39 single services and assigns capacities of six levels, ranging from a value of

- 0 = no relevant capacity of the land cover type to provide this particular ecosystem service,
- 1 = low relevant capacity,
- 2 = relevant capacity,
- 3 = medium relevant capacity,
- 4 = high relevant capacity and
- 5 = very high relevant capacity

to each CORINE Land Cover class to indicate their capacity for every ecosystem service.

In comparison to ecosystem services, landscape services more take into account spatial patterns, which result from human and natural processes, as well as the social dimension (Vallés-Planells et al. 2014). This makes the broader concept of landscape services better applicable and thus it is commonly used in landscape planning. As already described in detail in MaGICLandscapes' 'Green Infrastructure Handbook - Conceptual & Theoretical Background, Terms and Definitions' (John et al., 2019) we therefore applied the concept of landscape services. Based on de Groot (2006) landscape functions are grouped into five primary categories (based on de Groot 1992 and de Groot et al. 2002):

- **Regulation functions**: This group of functions relates to the capacity of natural and semi-natural ecosystems to regulate essential ecological processes and life support systems through biogeochemical cycles and other biospheric processes. Regulation functions maintain a *"healthy"* ecosystem on different scales and, at the biosphere level, provide and maintain the conditions for life on earth. In many ways, these regulation functions provide the necessary pre-conditions for all other functions. Thus, care should be taken not to double count their value in economic analysis. In theory, the number of regulation functions would be almost unlimited, but for landscape planning, only those regulation functions are considered that provide services, which have direct and indirect benefits to humans (such as maintenance of clean air, water and soil, prevention of soil erosion and biological control services)." (de Groot 2006, p. 177)
- **Habitat functions**: Natural ecosystems provide refuge and reproduction-habitat for wild plants and animals and thereby contribute to the (in situ) conservation of biological and genetic diversity and evolutionary processes. As the term implies, habitat functions relate to the spatial conditions needed to maintain biotic (and genetic) diversity and evolutionary processes. The availability, or condition, of this function is based on the physical aspects of the ecological niche within the biosphere. These requirements differ for different species groups, but can be described in terms of the carrying capacity and spatial needs (minimum critical ecosystem size) of the natural ecosystems which provide them." (De Groot 2006, pp. 177-178)
- **Production functions**: Photosynthesis and nutrient uptake by autotrophs converts energy, carbon dioxide, water and nutrients into a wide variety of carbohydrate structures, which are then used by secondary producers to create an even larger variety of living biomass. This biomass provides many resources for human use, ranging from food and raw materials (fibre, timber, etc.) to energy resources and genetic material." (De Groot 2006, p. 178)
- **Information functions**: Because most of human evolution took place within the context of undomesticated habitat, natural ecosystems provide an essential 'reference function' and contribute to the maintenance of human health by providing opportunities for reflection, spiritual enrichment, cognitive development, re-creation and aesthetic experience." (De Groot 2006, p. 178)
- **Carrier functions**: Most human activities (e.g. cultivation, habitation, transportation) require space and a suitable substrate (soil) or medium (water, air) to support the associated infrastructure. The use of carrier functions usually involves permanent conversion of the original ecosystem. Thus, the capacity of natural systems to provide carrier functions on a sustainable basis is usually limited (exceptions are certain types of shifting cultivation and transportation on waterways, which, on a small scale, are possible without permanent damage to the ecosystem)." (De Groot 2006, p. 178)

Therefore, the capacity values of the individual ecosystem services of Stoll et al. (2015) were matched to the corresponding terms of the de Groot et al. (2006) classification. As an intermediate result, a Europe-wide matrix with the reclassified terminology was produced, which served as a basis for the further discussion among the project partners, containing 1320 baseline values.

Subsequently, the matrix was edited in the first round of expert-based revision by the project partners. After the initial review round of adapting the values by each project case study area, the mean values for each capacity score were calculated. The resulting table was once again sent out to the project partners for discussion to come to a joint consensus. Eventually, the outliers, namely values that varied by more than ±2 from the original score, were analysed and the final value was defined.

The resulting final matrix of rated landscape services (Figure 20) could then be linked to the land cover classes of the case study areas on the transnational and regional scale in order to depict several aspects of landscape services from which humans benefit in multiple ways. This way the production of maps presenting the capacity of a landscape to provide single service or the mean value of a group of functions could be easily mapped.

CLC code	CLC description	**Regulation functions**	Gas regulation	Climate regulation	Disturbance prevention	Water regulation	Water supply	Soil retention	Soil formation	Nutrient regulation	Waste treatment	Pollination	Biological control	**Habitat functions**	Refugium function	Nursery function	**Production functions**	Food	Raw materials	Genetic resources	Medicinal resources	Ornamental resources	**Information functions**	Aesthetic information	Recreation	Cultural and artistic information	Spiritual and historic information	Science and education	**Carrier functions**	Habitation	Cultivation	Energy-conversion	Mining	Waste disposal	Transportation	Tourism-facilities	**Total Function Value**
111	Continuous urban fabric	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	3	4	2	0	2	5	0	1	0	0	3	2	**16**
112	Discontinuous urban fabric	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	2	3	3	4	2	0	1	4	0	1	0	0	3	2	**18**
121	Industrial or commercial units	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	4	0	1	0	0	3	0	**6**
122	Road and rail networks and associated land	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	1	0	0	0	0	0	5	2	**8**
123	Port areas	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	2	1	0	0	1	0	0	0	0	0	5	2	**8**
124	Airports	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	5	2	**7**
131	Mineral extraction sites	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	5	2	0	0	**4**
132	Dump sites	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	5	0	0	**3**
133	Construction sites	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	**1**
141	Green urban areas	2	2	4	1	2	1	2	1	1	2	1	1	2	2	1	0	0	1	0	0	1	2	3	5	3	0	1	1	0	1	0	0	0	0	4	**27**
142	Sport and leisure facilities	1	1	2	0	1	1	1	1	0	2	0	1	1	2	0	0	0	0	0	0	0	1	1	5	1	0	0	1	0	0	0	0	0	0	5	**16**
211	Non-irrigated arable land	1	1	3	1	3	0	1	2	1	1	1	2	2	2	2	2	5	2	2	1	1	1	2	1	3	0	1	1	0	5	0	0	0	0	0	**31**
212	Permanently irrigated land	2	1	3	1	4	0	1	2	1	1	1	2	2	2	2	2	5	2	2	1	1	1	2	1	3	0	1	1	0	5	0	0	0	0	0	**31**
213	Rice fields	2	1	3	1	4	1	1	2	2	1	1	2	4	3	4	2	5	2	2	1	1	2	3	1	4	2	2	1	0	5	0	0	0	0	0	**42**
221	Vineyards	2	1	3	1	3	1	2	3	1	1	1	1	2	2	2	2	5	3	2	1	1	3	3	3	4	3	2	1	0	5	0	0	0	0	1	**40**
222	Fruit trees and berry plantations	3	2	3	2	3	1	2	3	2	2	5	3	2	2	1	2	5	2	2	2	1	3	3	3	3	2	2	1	0	5	0	0	0	0	1	**40**
223	Olive groves	2	2	4	2	3	1	3	3	2	2	2	2	3	3	2	3	5	2	2	2	2	4	4	3	4	4	3	1	0	5	0	0	0	0	1	**48**
231	Pastures	3	1	3	1	3	1	4	4	2	3	3	3	4	4	3	3	5	2	3	3	1	3	4	4	3	1	3	1	0	5	0	0	0	0	1	**51**
241	Annual crops associated with permanent crops	2	1	3	1	3	1	2	3	1	1	3	2	2	2	2	2	4	3	1	3	1	2	2	2	3	1	2	1	0	4	0	0	0	0	1	**36**
242	Complex cultivation patterns	2	1	3	1	3	1	2	3	1	2	2	3	3	3	2	2	4	2	1	2	1	2	2	3	3	2	2	1	1	4	0	0	0	0	1	**39**
243	Land principally occupied by agriculture, with significant areas of natural vegetation	2	2	3	1	3	2	3	3	2	2	2	3	4	3	4	3	3	2	3	2	3	3	3	3	3	3	3	1	0	3	1	0	0	0	2	**49**
244	Agro-forestry areas	3	3	4	1	4	3	4	4	2	3	3	2	4	4	3	3	3	5	3	3	3	3	2	3	3	2	3	1	0	3	3	0	0	0	1	**54**
311	Broad-leaved forest	5	5	5	5	5	5	5	5	5	4	4	5	5	5	5	5	3	5	5	5	5	5	5	5	4	5	5	1	0	1	1	0	0	0	2	**79**
312	Coniferous forest	4	5	4	4	4	4	4	3	2	4	3	4	3	3	3	4	2	5	3	3	5	4	4	4	3	4	4	1	0	1	1	0	0	0	2	**78**
313	Mixed forest	5	5	5	4	5	5	5	5	5	4	4	5	5	5	5	4	3	5	5	4	5	5	5	5	4	4	5	1	0	1	1	0	0	0	2	**77**
321	Natural grasslands	4	3	3	3	4	4	5	5	4	3	4	4	5	5	5	3	2	1	5	3	4	5	5	5	4	4	5	0	0	1	0	0	0	0	1	**67**
322	Moors and heathland	4	3	4	4	4	4	5	5	4	3	3	4	5	5	5	3	2	3	5	3	4	5	5	5	4	4	5	0	0	0	1	0	0	0	1	**69**
323	Sclerophyllous vegetation	4	3	4	4	3	3	5	5	4	3	4	4	5	5	5	4	3	3	5	3	4	4	5	4	3	4	5	0	0	0	0	0	0	0	1	**67**
324	Transitional woodland-shrub	4	3	4	4	3	4	5	5	4	3	4	4	5	5	5	3	2	3	4	3	3	4	4	4	3	2	5	0	0	1	0	0	0	0	0	**63**
331	Beaches, dunes, sands	2	1	2	5	5	2	2	2	1	1	1	1	5	4	5	2	0	1	4	2	3	4	5	5	2	4	4	0	0	0	0	1	0	0	2	**52**
332	Bare rocks	0	0	0	1	1	1	0	0	0	0	1	0	3	4	1	2	0	0	3	2	3	3	4	4	0	5	4	0	0	0	0	0	0	0	2	**33**
333	Sparsely vegetated areas	1	1	1	1	1	2	1	1	1	1	2	1	4	4	4	2	0.	0	3	2	3	3	4	3	1	4	4	0	0	0	0	0	0	0	0	**40**
334	Burnt areas	0	0	0	0	0	0	0	1	1	0	1	1	2	1	2	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**10**
335	Glaciers and perpetual snow	1	1	3	0	4	5	0	0	0	0	0	1	2	2	2	1	0	0	2	0	3	4	5	5	1	5	4	0	0	0	0	0	0	0	2	**34**
411	Inland marshes	4	4	4	4	5	5	4	5	4	5	2	1	5	5	5	3	1	2	5	4	2	4	4	4	2	4	5	0	0	0	0	1	0	0	1	**63**
412	Peat bogs	4	4	5	3	4	4	5	5	4	4	1	3	5	5	4	2	0	4	4	3	1	4	4	4	2	4	4	1	0	0	2	2	0	0	1	**60**
421	Salt marshes	3	1	3	3	4	3	4	4	3	3	2	1	5	4	5	2	1	1	4	3	2	4	4	3	3	4	5	0	0	0	0	0	0	0	0	**53**
422	Salines	1	0	2	0	3	2	0	2	1	2	0	0	4	4	4	2	1	0	3	2	2	2	3	2	0	4	3	0	0	0	0	0	0	0	1	**37**
423	Intertidal flats	2	0	3	5	3	0	1	1	1	3	0	2	5	5	4	2	3	0	3	3	2	4	4	4	2	4	4	0	0	0	0	0	0	0	1	**49**
511	Water courses	3	2	4	3	4	5	2	1	3	5	0	3	5	5	5	3	3	2	5	3	4	5	5	5	4	5	5	1	0	0	4	0	0	3	3	**70**
512	Water bodies	3	2	4	3	4	5	3	4	3	5	0	3	5	5	5	3	3	2	5	3	3	5	4	5	4	5	5	1	0	0	3	0	0	3	3	**69**
521	Coastal lagoons	4	3	5	4	4	4	4	4	4	5	2	3	5	5	5	3	4	1	5	3	4	5	5	5	4	4	5	0	0	0	0	0	0	0	1	**68**
522	Estuaries	3	3	5	3	4	4	3	3	3	5	0	4	5	5	5	4	4	2	5	3	4	5	5	5	4	4	5	1	0	3	1	0	0	2	1	**70**
523	Sea and ocean	3	3	5	2	4	5	3	1	5	5	0	3	5	5	5	5	5	3	5	5	5	5	5	5	5	5	5	1	0	0	2	0	0	4	3	**77**

Figure 20: The final landscape services matrix including the resulting Total Function Value for each CORINE Land Cover class in central Europe.

The weighted values for each function group were calculated by dividing the actual sum of the capacity score within the main service by the highest possible score. Eventually, the total function value is the mean of the 5 weighted main service values, scaled on a basis from 0 to 100, where 0 means no capacity at all and 100 hypothetically represents land cover classes providing full capacity in each single service. This way the total function value represents the total amount of capacity of all landscape services, constituting a relevant indicator for multifunctionality of GI and landscape elements.

To consider the regional context, dependent on the available spatial and thematic resolution of geodata and the actual predominant land use, the intensity of management and general landscape characteristics, in specific cases individual adjustments assigning the capacity values on the regional dataset were made by the project partners.

For example, in the Austrian case study areas, the land cover class *'312 Coniferous forest'* was downgraded due to their occurrence as intensively managed monocultures of non-native spruce. Further the majority of intensively used vineyards and orchards is grassed in the case study area Kyjovsko (CZ) and therefore providing higher values of regulation functions. Due to this fact the land cover classes *'221 Vineyards'* and *'222 Fruit trees and berry plantations'* were valued higher than at central European level. The values for *'131 Mineral extraction sites'* were also increased, due to the regional occurrence of abandoned extraction sites with early succession series.

3.3.3.2 Regional Functionality Maps

By joining the final matrix with the spatial information using a GIS software (ArcGIS, QGIS), the GI's capacity of the 30 single landscape services, the five main services and the total function value within the case study areas, are displayed based on the CORINE Land Cover data at transnational and regional level.

This allows the detection of areas of interest regarding different services or the overall multifunctionality in order to develop specific management strategies at a regional and local level to manage existing or implement potential GI. The recognition and mapping GI elements and their capacity to deliver a whole range of services allows to enhance the regional applicability and acceptance of GI initiatives and provides a crucial foundation for developing evidence-based strategies and action plans through stakeholder involvement to direct future actions and investment in GI.

These various service maps could be used alone or in combination with other services maps to identify undersupplied regions, important functional spaces or areas of high potential for relinking of ecological systems, based on the evaluation results and the respective colouration. In the following, selected results of the case study areas are depicted.

The following groups of landscape services, expressed by the mean value derived from the respective series of individual services, which could be also mapped as single services depending on the particular interest and problem, are summarised and mapped below:

- Regulation functions: Gas regulation, Climate regulation, Disturbance prevention, Water regulation, Water supply, Soil retention, Soil formation, Nutrient regulation, Waste treatment, Pollination, Biological control (Figure 21)
- Habitat functions: Refugium function, Nursery function (Figure 22)
- Production functions: Food, Raw materials, Genetic resources, Medicinal resources, Ornamental resources (Figure 23)
- Information functions: Aesthetic information, Recreation, Cultural and artistic information, Spiritual and historic information, Science and education (Figure 24)
- Carrier functions: Habitation, Cultivation, Energy-conversion, Mining, Waste disposal, Transportation, Tourism-facilities (Figure 25)

  as well as

- Total function value: mean of the 5 weighted main service values (Figure 26) to aggregate the groups of landscape services.

The selected examples of functionality maps below provide easy-to-communicate results of the landscape's capacities to provide certain services ranging from red, representing a value of 0 and no relevant capacity of the land cover type to provide this particular landscape service, to green constituting a value of 5 with very high relevant capacity.

This way hot spots and cold spots in the provision of these services are highlighted and serves as a key planning and decision-taking basis to develop regional strategies and action plans for future actions and investments in GI.

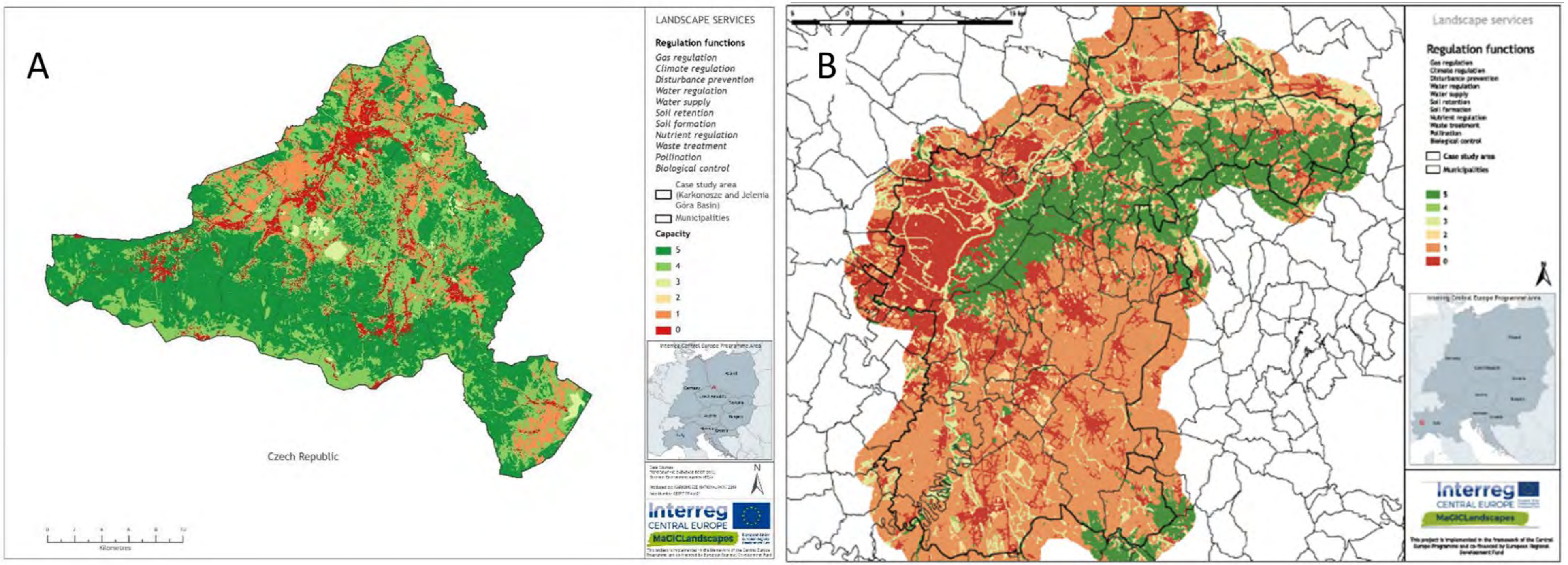

Figure 21: Results of the mapping of the main Regulation functions based on the regional dataset for the case study areas Karkonosze National Park (PL) (A) and Po Hills around Chieri (IT) (B).

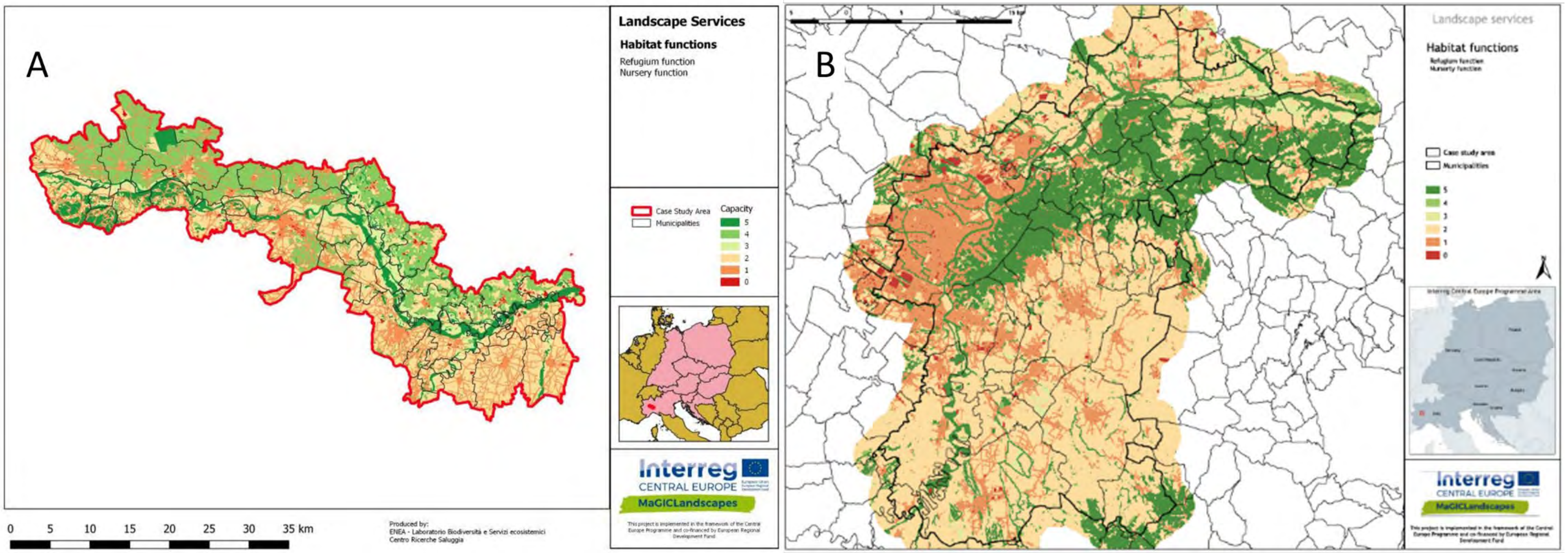

Figure 22: Results of the mapping of the main Habitat functions based on the regional dataset for the case study areas Upper Po plain (IT)(A) and Po Hills around Chieri (IT)(B).

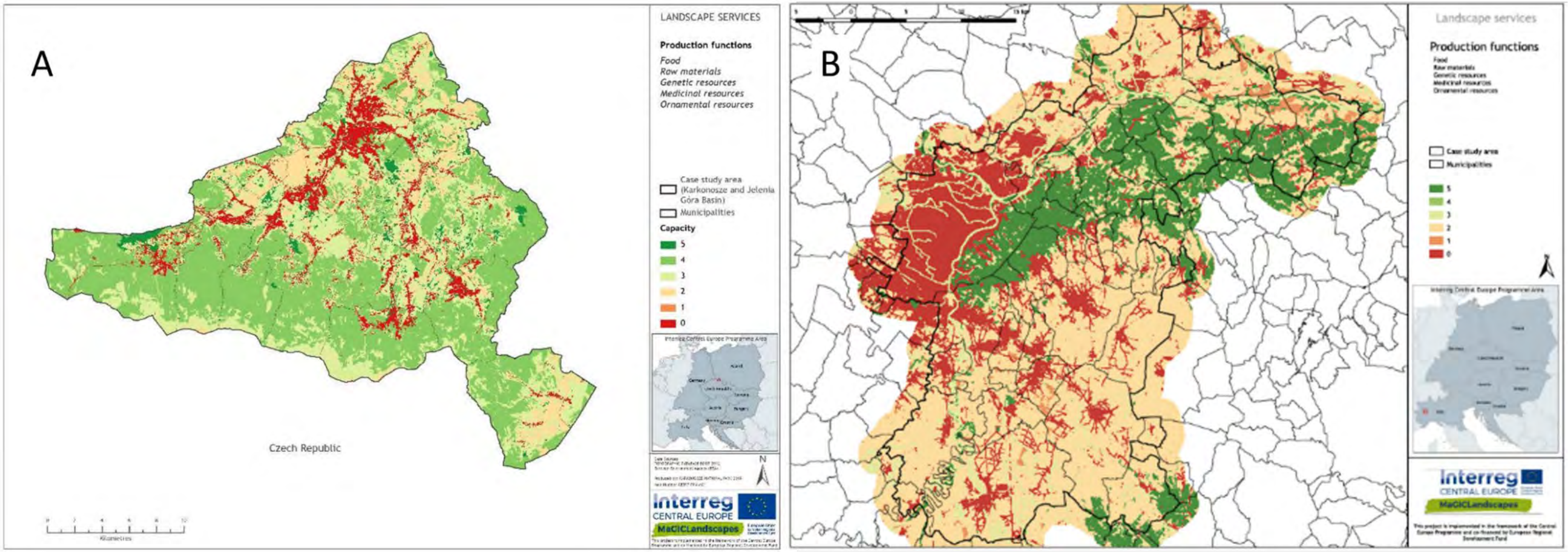

Figure 23: Results of the mapping of the main Production functions based on the regional dataset for the case study areas Karkonosze National Park (PL)(A) and Po Hills around Chieri (IT)(B).

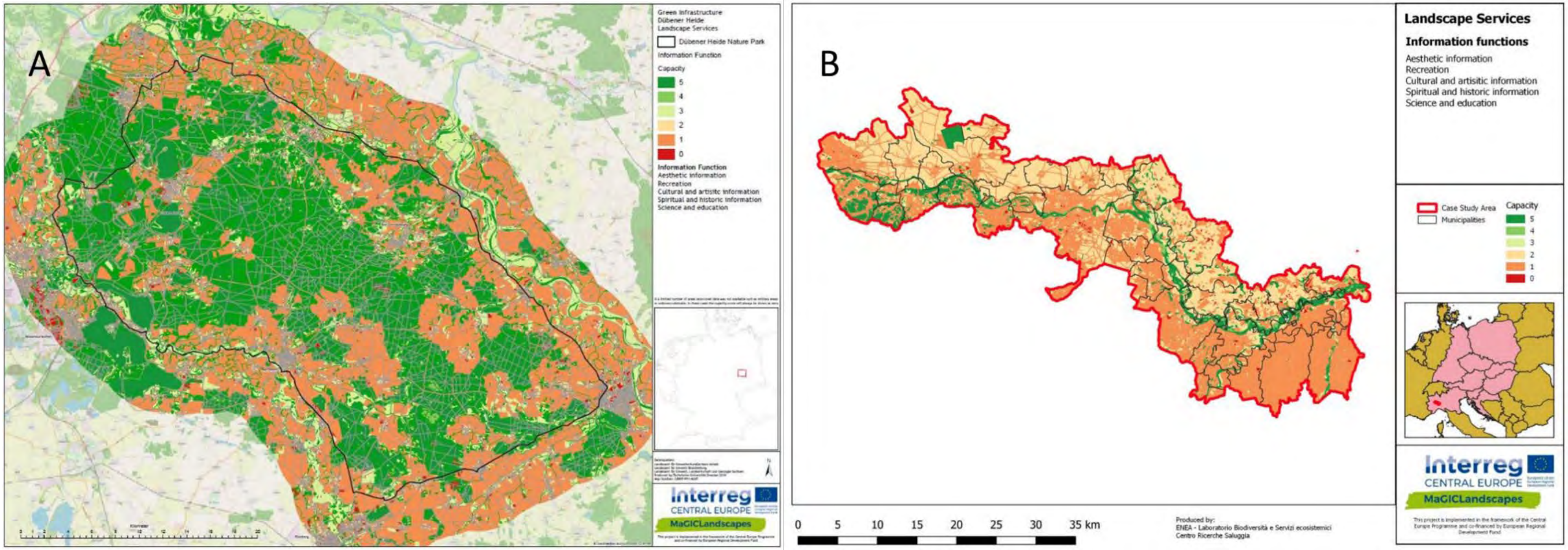

Figure 24: Results of the mapping of the main Information functions based on the regional dataset for the case study areas Dübener Heide Nature Park (DE) (A) and Upper Po plain (IT) (B).

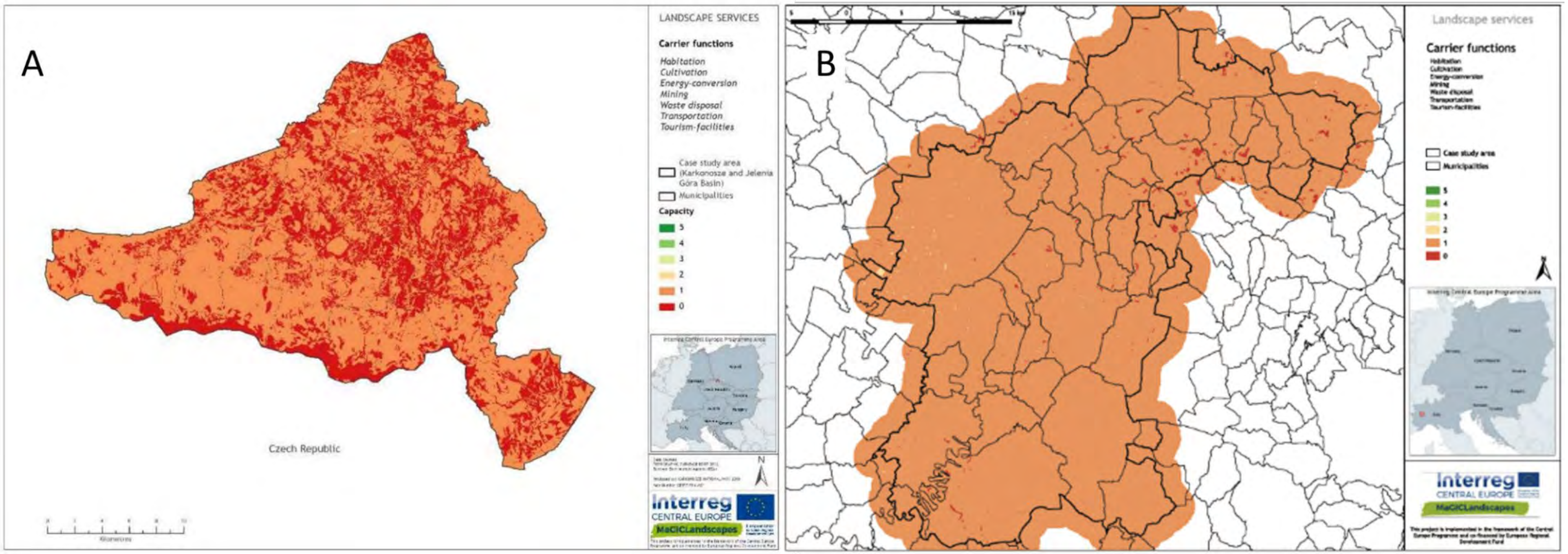

Figure 25: Results of the mapping of the main Carrier functions based on the regional dataset for the case study areas Karkonosze National Park (PL)(A) and Po Hills around Chieri (IT)(B).

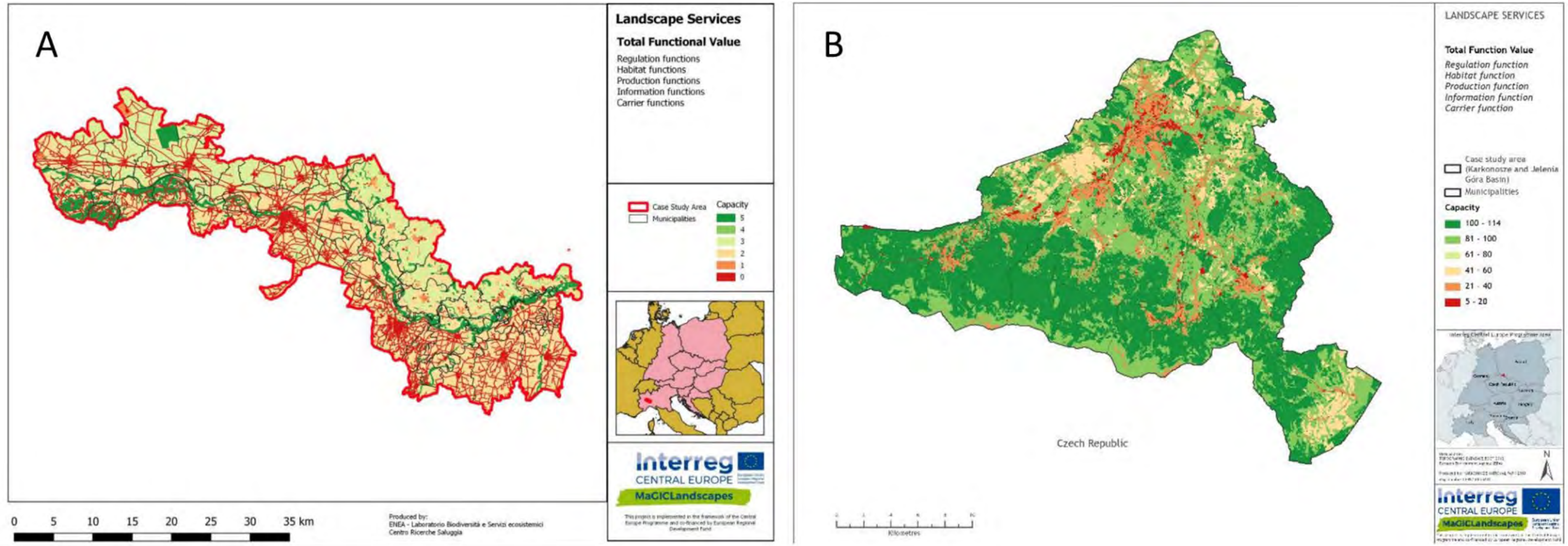

Figure 26: Results of the mapping of the Total Function Value based on the regional dataset for the case study areas Upper Po plain (IT)(A), and Karkonosze National Park (PL)(B)

CLC code	CLC description	Carrier functions: mean value	Carrier functions: normalized sum	Habitation	Cultivation	Energy-conversion	Mining	Waste disposal	Transportation	Tourism-facilities
111	Continuous urban fabric	2	5	5	0	1	0	0	3	2
112	Discontinuous urban fabric	1	5	4	0	1	0	0	3	2
121	Industrial or commercial units	1	4	4	0	1	0	0	3	0
122	Road and rail networks and associated land	1	3	0	0	0	0	0	5	2
123	Port areas	1	3	0	0	0	0	0	5	2
124	Airports	1	3	0	0	0	0	0	5	2
131	Mineral extraction sites	1	3	0	0	0	5	2	0	0
132	Dump sites	1	2	0	0	0	0	5	0	0
133	Construction sites	0	0	0	0	0	1	0	0	0
141	Green urban areas	1	2	0	1	0	0	0	0	4
142	Sport and leisure facilities	1	2	0	0	0	0	0	0	5
211	Non-irrigated arable land	1	2	0	5	0	0	0	0	0
212	Permanently irrigated land	1	2	0	5	0	0	0	0	0
213	Rice fields	1	2	0	5	0	0	0	0	0
221	Vineyards	1	3	0	5	0	0	0	0	1
222	Fruit trees and berry plantations	1	3	0	5	0	0	0	0	1
223	Olive groves	1	3	0	5	0	0	0	0	1
231	Pastures	1	3	0	5	0	0	0	0	1
241	Annual crops associated with permanent crops	1	2	0	4	0	0	0	0	1
242	Complex cultivation patterns	1	3	1	4	0	0	0	0	1
243	Land principally occupied by agriculture, with significant areas of natural vegetation	1	3	0	3	1	0	0	0	2
244	Agro-forestry areas	1	3	0	3	3	0	0	0	1
311	Broad-leaved forest	1	2	0	1	1	0	0	0	2
312	Coniferous forest	1	2	0	1	1	0	0	0	2
313	Mixed forest	1	2	0	1	1	0	0	0	2
321	Natural grasslands	0	1	0	1	0	0	0	0	1
322	Moors and heathland	0	1	0	0	1	0	0	0	1
323	Sclerophyllous vegetation	0	0	0	0	0	0	0	0	1
324	Transitional woodland-shrub	0	0	0	1	0	0	0	0	0
331	Beaches, dunes, sands	0	1	0	0	0	1	0	0	2
332	Bare rocks	0	1	0	0	0	0	0	0	2
333	Sparsely vegetated areas	0	0	0	0	0	0	0	0	0
334	Burnt areas	0	0	0	0	0	0	0	0	0
335	Glaciers and perpetual snow	0	1	0	0	0	0	0	0	2
411	Inland marshes	0	1	0	0	0	1	0	0	1
412	Peat bogs	1	2	0	0	2	2	0	0	1
421	Salt marshes	0	0	0	0	0	0	0	0	0
422	Salines	0	0	0	0	0	0	0	0	1
423	Intertidal flats	0	0	0	0	0	0	0	0	1
511	Water courses	1	5	0	0	4	0	0	3	3
512	Water bodies	1	4	0	0	3	0	0	3	3
521	Coastal lagoons	0	0	0	0	0	0	0	0	1
522	Estuaries	1	3	0	3	1	0	0	2	1
523	Sea and ocean	1	4	0	0	2	0	0	4	3

Since the group of Carrier functions only refer to cultural landscapes representing mutually exclusive forms of land use (e.g. mining, waste disposal, transportation, tourism facilities, cultivation, habitation), the averaging of one or a few effective single services with a majority of unavailable services does not allow for an illustrative, differentiated representation of these human activities in the landscape (Figure 25). Therefore, the calculation of the value for this group of services was adapted additionally, by normalizing the sum of all single services' capacities relative to the top-rated land use class.

Thereby the differences and patterns in the provision of carrier functions of a certain landscape can be displayed more adequately, highlighting areas consumed by cultural usage (Figure 28) and supporting the applicability of the produced maps in landscape and spatial planning greatly.

Figure 27: Alternative calculation of the group value for Carrier functions by normalizing the sum of all single services' capacities relative to the top-rated land use class.

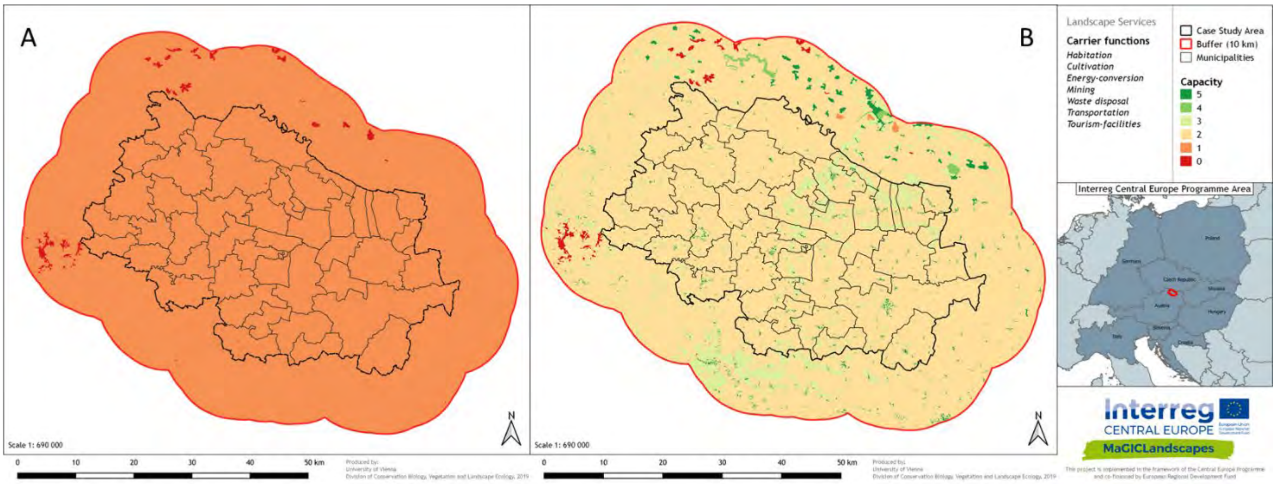

Figure 28: Exemplary comparison of the group value for Carrier functions based on the mean value (A) and the normalized sum (B) for the Austrian case study area "Eastern Waldviertel & Western Weinviertel"

4 Conclusions on the mapping method and the usability of the methods and maps

Based on the objective to implement green infrastructure in central European planning policies the MaGICLandscapes project aimed to operationalise the GI concept in central Europe as well as in nine case study areas, by using a suite of GIS-based analysis methods, to provide land managers, policy makers and communities with the adequate tools and knowledge, at different spatial levels.

We found that the detailed representation of the regional GI network allows to enhance the regional applicability and acceptance of GI initiatives and provides a crucial foundation for assessing GI connectivity and functionality. Based on that well-founded strategies and action plans can be best developed through an intensive stakeholder involvement to direct future actions and investments in GI.

Therefore, GI assessment methods that focus on functionality in terms of connectivity and provision of landscape services were developed to communicate and facilitate the adoption of those assessment methods by institutions through stakeholder involvement and participatory approaches in order to implement and maintain a viable GI network.

Following the objectives and ideas of MaGICLandscapes of an integrated, cross-sectoral approach employing stakeholder involvement and participatory processes, the partner consortium defined an expert based classification of GI based on CLC classes for the whole Central European Programme Area as a first step, followed by a round of stakeholder validation in the course of workshops in the case study areas to adapt the definitions and classification regionally. The implementation of project activities demonstrated the necessity for a detailed regional GI data basis to allow the realisation of the assessment methods and objectives stated above in the first place.

EU-wide available land cover maps, like CORINE (CLC), can help in coarse assessments of GI connectivity and functionality, but they cannot provide exact information about the local network of GI elements. Therefore, this data basis should be supplemented by more detailed available national and regional data. This approach could be adopted all over Europe, owing to the availability of similar kinds of detailed datasets (e.g. agricultural, digital cadastral and hydrographical data). The regional GI map and its various analysis products can be related to a variety of spatial planning measures, enabling politicians, planners, land users/managers and communities to invest in GI by highlighting hot spots of highly fragmented areas or those dominated by well-established networks of GI as well as locating focus areas providing or in need of capacities of certain ecosystem services, influencing the well-being of individuals and communities.

When it comes to interventions or implementation measures at the local level, the ground-truthing through field mapping of selected test sections revealed the need for a local assessment of GI in terms of biodiversity, naturalness and structure in addition to desk-based GIS analysis. Therefore, the EUNIS habitat classification (2017) provides a characterisation of GI that is comparable at the international level and also transferable to national classification schemes.

In the synopsis of the various products of the assessment and mapping of green infrastructure functionality and connectivity in a certain region, the needs and opportunities for GI become apparent, justifying investments in GI. This inventory of GI regarding its spatial structure, functionality and ecosystem services allows for considering cross-sectoral policy and planning objectives including the GI concept into regional and spatial planning.

In conclusion, the following steps in the procedure of green infrastructure functionality assessment and mapping are recommended and explained in detail above:

1. Definition of green and blue infrastructure elements representing the objects of interest at regional level
2. Data acquisition at transnational, regional and local level
3. Generating transnational, regional and local maps of GI functionality for the case study areas
    - Connectivity analysis
        - MSPA (Morphological Spatial Pattern Analysis)
        - Network analysis
        - Euclidean Distance
    - Field mapping methodology
        - Identification of elements of GI on the local level
            - EUNIS habitat classification
            - determination of hemerobiotic state or the level of naturalness
            - Mapping of barriers
    - Functionality analysis
        - Preparation of landscape service capacity matrix
        - Individual expert-based revision
        - Final matrix based on joint consensus discussion
        - Maps demonstrating functionality – Regional level

References

Benedict, M. A., and McMahon, E. T. (2002): Green infrastructure: smart conservation for the 21st century. Renewable resources journal, 20(3), 12-17.

Burkhard B., Kroll F., Müller F., Windhorst W. (2009): Landscapes' capacities to provide ecosystem services – a concept for land cover based assessments. Landscape Online 15, 1–22.

Burkhard B., Kroll F., Nedkov S., Müller F. (2012): Mapping ecosystem service supply, demand and budgets. Ecol. Indic. 21, 17–29.

Campagne, C. S., Roche, P., Gosselin, F., Tschanz, L., & Tatoni, T. (2017): Expert-based ecosystem services capacity matrices: Dealing with scoring variability. Ecological Indicators, 79, 63-72.

Davies, C. E., & Moss, D. (1999): EUNIS habitat classification. Final report to the European Topic Centre on Nature Conservation. European Environment Agency, 256.

Davies, C. E., Moss, D., Hill, M. O. (2004): EUNIS habitat classification revised 2004. Report to: European Environment Agency-European Topic Centre on Nature Protection and Biodiversity, 127-143.

de Groot R. S. (2006): Function-analysis and valuation as a tool to assess land use conflicts in planning for sustainable, multifunctional landscapes. Landscape and Urban Planning 75:175-186.
Published online: **http://dx.doi.org/10.1016/j.landurbplan.2005.02.016**

de Groot R. S., Alkemade R., Braat L., Hein L., Willemen L. (2010): Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. Ecological Complexity 7:260-272. Published online: **http://dx.doi.org/10.1016/j.ecocom.2009.10.006**

de Groot R. S., Wilson M. A., Boumans R. M. J. (2002): A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecological Economics 41(3):393-408. Published online: **http://dx.doi.org/10.1016/S0921-8009(02)00089-7**

European Commission (2016): Green Infrastructure. Published online: **http://ec.europa.eu/environment/nature/ ecosystems/index_en.htm** (last accessed 12.08.2018)

European Environment Agency (EEA) (2009): A crosswalk between EUNIS habitats Classification and Corine Land Cover, Published online: **https://www.eea.europa.eu/data-and-maps/data/eunis-habitat-classification/documentation/eunis-clc.pdf** (last accessed 22.11.2019)

European Environment Agency (EEA) (2014): Spatial analysis of green infrastructure in Europe. EEA Technical report, No 2/2014, Publications Office of the European Union, Luxembourg, Published online: **https://www.eea.europa.eu/publications/spatial-analysis-of-green-infrastructure/at_download/file** (last accessed 22.11.2018)

EEA – Copernicus Land Monitoring Services (2016): GIOland (GMES/Copernicus initial operations land) High Resolution Layers (HRLs) - summary of product specifications. Published online: **https://cws-download.eea.europa.eu/pan-european/hrl/HRL_Summary_for_publication_ v14.pdf** (last accessed 02.11.2017)

EEA (2017): Crosswalk between EUNIS habitats classification and CORINE Land Cover. Published online: **https://www.eea.europa.eu/data-and-maps/data/eunis-habitat-classification/documentat ion/eunis-clc.pdf**

Feranec, J.; Soukup, T.; Hazeu, G.; Jaffrain, G. (2016): European Landscape Dynamics: CORINE Land Cover Data. CRC Press, Boca Raton, 337 p.

Kopperoinen, L., Itkonen, P., and Niemelä, J. (2014): Using expert knowledge in combining green infrastructure and ecosystem services in land use planning: an insight into a new place-based methodology. Landscape Ecology, 29(8), 1361-1375.

Millennium Ecosystem Assessment (2005): Ecosystems and Human Well-being: Synthesis. Island Press. Washington, DC.
Published online: **http://www.millenniumassessment.org/documents/document.356.aspx.pdf**

Neubert, M., John, H. (ed., 2019). Manual of Transnational Green Infrastructure Assessment – Decision Support Tool. Interreg Central Europe Project MaGICLandscapes. Output O.T1.2, Dresden. With contributions from: M. Neubert, H. John, S. Alberico., G. Bovo, S. Ciadamidaro, F. Danzinger, M. Erlebach, D. Freudl, S. Grasso, A. Hahn, Z. Jała, I. Lasala, C. Marrs, M. Minciardi, G. L. Rossi, H. Skokanová, T. Slach, K. Uhlemann, P. Vayr, D. Wojnarowicz, T. Wrbka. Published online: **https://www.interreg-central.eu/Content.Node/MaGICLandscapes.html#Outputs**

John, H, Marrs, C., Neubert, M. (ed., 2019): Green Infrastructure Handbook - Conceptual and Theoretical Background, Terms and Definitions. Interreg Central Europe Project MaGICLandscapes. Output O.T1.1, Dresden. With contributions from: H. John, C. Marrs, M. Neubert, S. Alberico, G. Bovo, S. Ciadamidaro, F. Danzinger, M. Erlebach, D. Freudl, S. Grasso, A. Hahn, Z. Jała, I. Lasala, M. Minciardi, G.L. Rossi, H. Skokanová, T. Slach, K. Uhlemann, P.Vayr, D. Wojnarowicz, T. Wrbka. Published online: **https://www.interreg-central.eu/Content.Node/MaGICLandscapes.html#Outputs**

Pakzad, P., and Osmond, P. (2016): Developing a sustainability indicator set for measuring green infrastructure performance. Procedia-social and behavioural sciences, 216, 68-79.

Paracchini, M. L., and Capitani, C. (2011): Implementation of an EU wide indicator for the rural-agrarian landscape. Water. doi, 10, 25137.

Qureshi, S., Kazmi, S. J. H., and Breuste, H. J. 2010: Ecological disturbances due to high cutback in the green infrastructure of Karachi: Analyses of public perception about associated health problems. Urban Forestry and Urban Greening, 9(3), 187-198.

Saura, S., & Rubio, L. (2010): A common currency for the different ways in which patches and links can contribute to habitat availability and connectivity in the landscape. Ecography, 33(3), 523-537.

Saura, S., Vogt, P., Velázquez, J., Hernando, A., & Tejera, R. (2011): Key structural forest connectors can be identified by combining landscape spatial pattern and network analyses. Forest Ecology and Management, 262(2), 150-160.

Soille, P., & Vogt, P. (2009): Morphological segmentation of binary patterns. Pattern recognition letters, 30(4), 456-459.

Stoll S., Frenzel M., Burkhard B., Adamescu M., Augustaitis A., Baeßler C., Boneth F.J., Carranza M.L., Cazacu C., Cosor G.L., Díaz-Delgado R., Grandin U., Haase P., Hämäläinen H., Loke R., Müller J., Stanisci A., Staszewski T., Müller F. (2015): Assessment of ecosystem integrity and service gradients across Europe using the LTER Europe network. Ecological Modelling, Volume 295, Pages 75-87. Published online: **https://doi.org/10.1016/j.ecolmodel.2014.06.019**

Sukopp, H. (1969): Der Einfluss des Menschen auf die Vegetation, [Human impact on the vegetation]. Vegetation, 17, 360–371.

TEEB (2010): The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A synthesis of the approach, conclusions and recommendations of TEEB.

Vallés-Planells M., Galiana F., and Van Eetvelde V. (2014): A classification of landscape services to support local landscape planning. Ecology and Society 19(1): 44. Published online: **http://dx.doi.org/10.5751/ES-06251-190144**

Vogt, P., Riitters, K. H., Iwanowski, M., Estreguil, C., Kozak, J., & Soille, P. (2007): Mapping landscape corridors. Ecological Indicators, 7(2), 481-488.

Vogt, P., & Riitters, K. (2017): GuidosToolbox: universal digital image object analysis. European Journal of Remote Sensing, 50(1), 352-361.

Walz, U., & Stein, C. (2014): Indicators of hemeroby for the monitoring of landscapes in Germany. Journal for Nature Conservation, 22(3), 279-289.

Wickham, J. D., Riitters, K. H., Wade, T. G., & Vogt, P. (2010): A national assessment of green infrastructure and change for the conterminous United States using morphological image processing. Landscape and Urban Planning, 94(3-4), 186-195.