Assessment of the ecosystem services given by rural and urban green areas to preserve high-quality territories from land take: the case of the province of Monza Brianza (Italy)

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Abstract

Rural and urban green areas are essential territories that support life and ecosystems. The significant reduction of these areas due to urbanization is a pressing issue. The process of land take consumes not only land resources but also the connected ecosystems and the benefits generated for human society. Reducing the quantity of land taken is imperative, but preserving high-quality territories is essential to achieving sustainable development. Evaluating the quality of non-urbanized areas can be done by assessing the ecosystem services (ESs) provided by these areas. In this paper, the authors present a further step: an evolution and deepening of the previous methodology (published in 2020) to evaluate the quality of rural and urban green areas through the assessment of the ESs provided. The methodology first allows the identification of the ESs provided by different typologies of rural and urban green areas according to the common international classification of ESs (provisioning, regulation and maintenance, and cultural). Then, it allows the calculation of several singular indexes and a final composite quality index through the use of geographical information systems. An analytic hierarchy process was performed with the creation of different scenarios to consider the different importance of the singular indexes assigned by planners and communities involved.

The methodology was applied to the province of Monza Brianza (Italy), for testing and validation purposes. The application to the municipality of Sovico, which is presented in this report, allowed for the identification of areas with higher quality in the different scenarios that were created to consider the relative importance of the territorial characteristics.

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Introduction

Non-urbanized areas, including residual urban green areas, urban parks, agricultural lands, natural areas, and semi-natural areas, are a crucial part of the green infrastructure. They are essential in supporting life and the future development of human society (Weber *et al.,* 2006; Tzoulas *et al.,* 2007; European Union, 2014; La Rosa and Privitera, 2013; Fairbrass *et al.*, 2018).

Through various chemical, physical, and biological processes, the natural heritage can provide long-term benefits that enhance the quality of human life. However, these benefits can only be sustained if the natural heritage is conserved over time and not consumed (Costanza *et al*., 1997), following the well-known principle of sustainable development.

Despite their vital role in ensuring the well-being of the population, green areas are continuously being consumed by the process of land take, which involves the irreversible transformation of natural or agricultural land into urbanized areas (Colsaet *et al.*, 2018; Arcidiacono *et al.*, 2018). Land take can be defined as "the change in the amount of agricultural, forest and other semi-natural and natural land taken by urban and other artificial land development. It includes areas sealed by construction and urban infrastructure, as well as urban green areas, and sport and leisure facilities" (European Environmental Agency, 2019).

The process of land take not only consumes the land resource but also destroys the connected ecosystems and the benefits they provide to human society, known as ecosystem services (ESs) (MEA, 2005; Tassinari *et al*., 2013; Senes and Cirone, 2018).

Reducing the amount of land taken is an imperative action, and many countries have adopted various planning strategies

(Rodela *et al.*, 2019; Ledda *et al.*, 2023) and reduction thresholds to achieve the European Union's target of 0 net land take by 2050 (European Commission, 2016). However, this approach is not enough to counteract the loss of benefits provided to human society by the "taken" green areas and their related natural, cultural, and landscape resources.

In addition to quantitative aspects, qualitative ones must also be considered. The types and amounts of ESs lost due to the consumption of a portion of land depend on the territorial quality (Ronchi *et al*., 2019). In this sense, the Lombardy Region has introduced, in addition to quantitative thresholds of land take reduction, an obligation for municipalities to assess the quality of non-urbanized areas in their land use plan. This assessment includes evaluating the agricultural, pedological, naturalistic, and landscape values (Lombardy Region, 2014; Senes *et al*., 2020). Assessing the ESs provided by urban and rural green areas can be a valuable approach to evaluating the overall quality of the territory (Koschke *et al.*, 2012; Logsdon and Chaubey, 2013; Albert *et al*., 2016; De Montis *et al.*, 2020).

In this framework, the goals of this study are: i) to develop a methodology for the assessment of the quality of non-urbanized areas based on the evaluation of the ESs provided; ii) to validate the methodology through an application at the municipal level.

Starting from the results of a previous study that defined a land quality index to preserve the best territories from future land take (Senes *et al.*, 2020), this present study modifies and deepens the methodology for assessing the ESs provided by non-urbanized territories. It proposes a procedure to define and calculate the provisioning ESs related to agricultural activity, regulation of ESs related to soil and natural resources, and cultural ESs related to landscape resources, as well as an overall composite quality index (CQI). Moreover, the proposed methodology attempts to take into account the fact that the assessment of the overall quality of a territory depends not only on the characteristics of the territory itself but also on the importance that each considered factor assumes in the particular place and time where the evaluation takes place.

In a "participatory" approach (Senes *et al.*, 2012), it is important to find a way to incorporate the needs and desires of the local community into the planning process. This can be considered a multiple criteria decision making (MCDM) problem since it involves assessing criteria that may conflict with each other (Malczewski, 2004; Fumagalli *et al.*, 2017; Türk, 2018) and allows

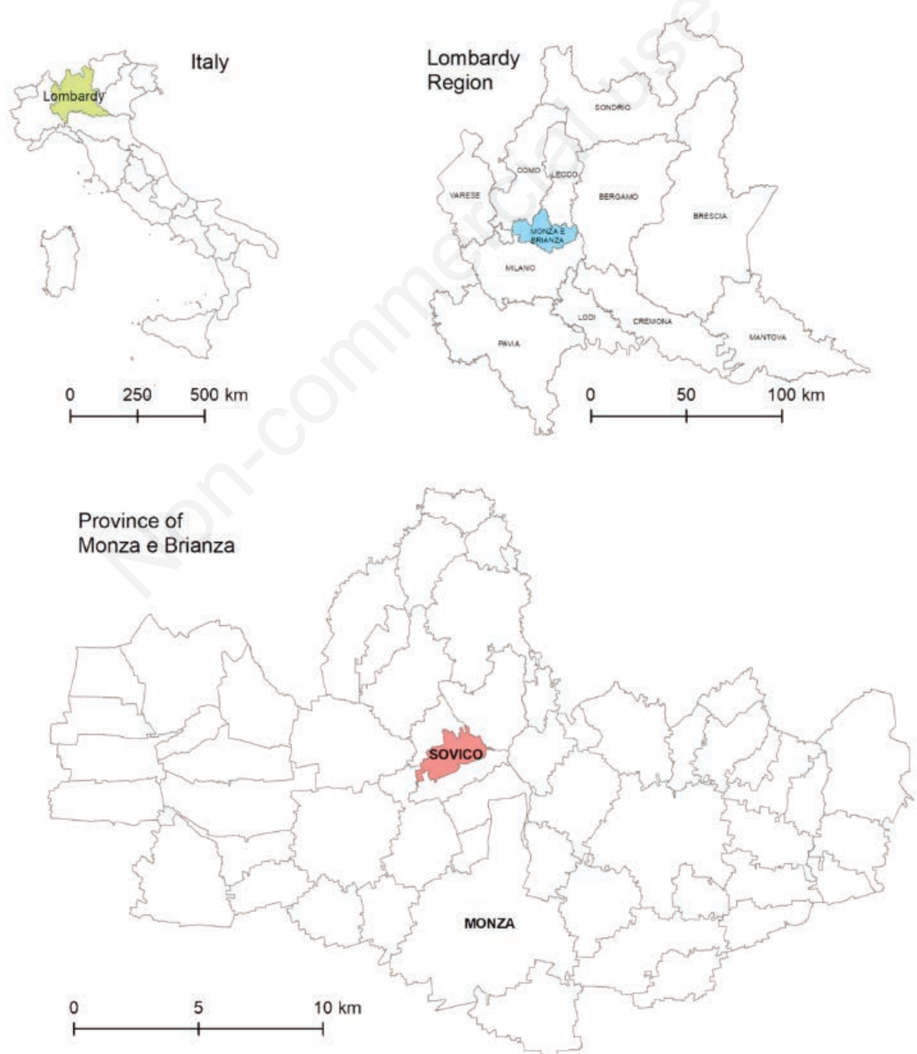


Figure 1. Study area.

for explicit stakeholder involvement (de Groot *et al.*, 2010; Burkhard *et al.*, 2012).

In this study, the authors performed an analytic hierarchy process (AHP) with the creation of different scenarios to take into account the varying importance of the individual indexes assigned by planners and communities involved. AHP, introduced by Saaty (1980), is one of the most widely used MCDM tools by researchers and decision-makers in different fields (Itami *et al.*, 2001; Higgs, 2006; Dos Santos *et al.*, 2019). AHP is a quantitative method for selecting alternatives based on their relative importance with respect to different criteria (Boroushaki and Malczewski, 2008) through pairwise comparison according to the Saaty 9-point individual judgment scale (Saaty, 1980; Koschke *et al.*, 2012). AHP can also be easily incorporated into geographical information system (GIS) procedures (Seyedmohammadi *et al.*, 2019) to calculate the weights to be associated with the various attributes of map layers (Mosadeghi *et al.*, 2015; Rovelli *et al.*, 2020).

The defined methodology was applied at the municipal level to the province of Monza Brianza (Italy) using GIS and geographic data from regional, provincial, municipal, and Valle Lambro Park databases.

Materials and Methods

The study area is the province of Monza Brianza, which includes 55 densely populated municipalities with a high level of urbanization, located north of Milan. The method is applied at the municipal level, and this paper refers to the application in the municipality of Sovico (area 324.9 ha) (Figure 1).

The methodology consists of 3 main steps, each of which is divided into one or more phases (Figure 2).

Step 1 is the preliminary step. It includes: i) phase 1: definition of the ESs provided by non-urbanized areas; ii) phase 2: creation of the land use map of non-urbanized areas; iii) phase 3: choice of the layers to be used for the calculation of the indexes.

Step 2 is the index calculation. It includes: i) phase 4: assessment of the provisioning ESs related to agricultural activity (I_Prov_Agr index); ii) phase 5: assessment of the regulation ESs related to soil characteristics (I_Reg_Soil index); iii) phase 6: assessment of the regulation ESs related to natural resources (I_Reg_Nat index); iv) phase 7: assessment of the cultural ESs related to landscape resources (I_Cult_Land index).

Step 3 is the composite index, and it includes phase 8, namely the assessment of the CQI for different scenarios.

Phase 1: definition of the ecosystem services provided by non-urbanized areas

The Lombardy Region's identified territorial peculiarities, including agricultural, pedological, naturalistic, and landscape, have been used as a reference to define the ESs provided by non-urbanized areas. The latest version (V5.1) of the common international classification for ESs (CICES) has been used. The ESs considered have been aggregated at the "group" level (Haines-Young and Potschin, 2018) (Figure 3).

Phase 2: creation of the land use map of non-urbanized areas

The starting point of the evaluation procedure is the identification of non-urbanized areas. Two vector databases produced by the Lombardy Region have been considered to produce the map: the regional topographical database (DBT) and the agricultural and forestry land use database (DUSAF).

DBT represents the base map of the regional information system at the municipal level (Lombardy Region, 2005). It is produced at a 1:2000 scale and includes a series of layers that represent the different elements of the territory (buildings, transport network, hydrography, orography, green areas, agricultural areas, woods, vegetation, *etc.*). DUSAF, produced at 1:10,000 scale, contains a detailed classification of land uses (both urbanized and not urbanized areas) with specific reference to agriculture and forestry uses. In this study, both databases were used, and a specific procedure was defined to integrate the 2 data sources. DBT was used as the graphical base due to its greater definition of the geometrical and spatial characteristics of the land use polygons. DUSAF was

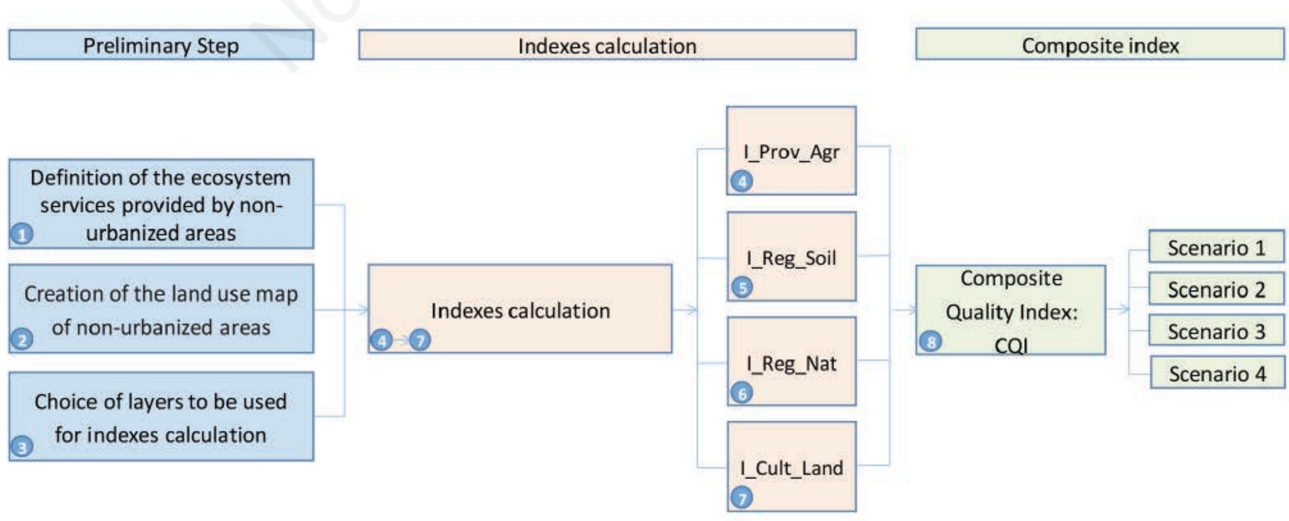


Figure 2. Methodological scheme.

chosen as the information source only for extra-urban areas since it is more precise and up-to-date for agroforest areas. The procedure defined includes the following stages (Figure 4): i) selection of the non-urbanized areas from DBT; ii) check using satellite images; iii) overlay mapping with non-urbanized areas from the DUSAF; iv) homogenization and definitive classification definition. Initially (i), polygons classified as non-urbanized areas were selected from DBT. Polygons with "particular" land use classes (uncertain or in-progress land uses) were added to the selection to verify them. The selected polygons were checked (ii) using the most recent satellite images (2021-2022) to find and correct errors.

The corrected polygons were combined with the non-urbanized polygons of the DUSAF through a topological overlay in the GIS environment (iii). In this way, the information contained in the DUSAF (generally more up-to-date and specific for green areas) was associated with the polygons obtained in the previous stages ("i" and "ii"). The necessary "editing operations" were performed on small "sliver polygons" resulting from the overlay process. Finally, the definitive classification was defined (iv) through a homogenization process in which the extra-urban polygons were assigned to the corresponding land use class of the DUSAF classification. The final map is represented in Figure 5.

Phase 3: choice of the layers to be used for the calculation of the indexes

For each ES, the information layers to be used for the calculation of the relative index have been identified. The databases used are derived from regional, provincial, and municipal sources, particularly the geoportals of the Lombardy Region and the province of Monza Brianza. For the assessment of the provisioning ESs related to agricultural activity (I_Prov_Agr index), agricultural land use classes from DUSAF have been used, along with the belonging of the farm to the official register of agricultural companies of the Lombardy Region [regional agricultural information system (SIARL)]. The ESs provided refer to the following "sections" of the CICES (*Supplementary Table 1*): provisioning (biotic), and regulation & maintenance (biotic). For the assessment of the regulation ESs related to the soil characteristics (I_Reg_Soil index), a complex set of information derived from different databases has been used: i) land capability, soil attitude for spreading slurry or urban sewage sludge, soil capacity for surface water or groundwater protection (Lombardy Region); ii) underground cavities (province of Monza); iii) geological limitations, protection zones of wells (municipalities); iv) green infrastructure suitability

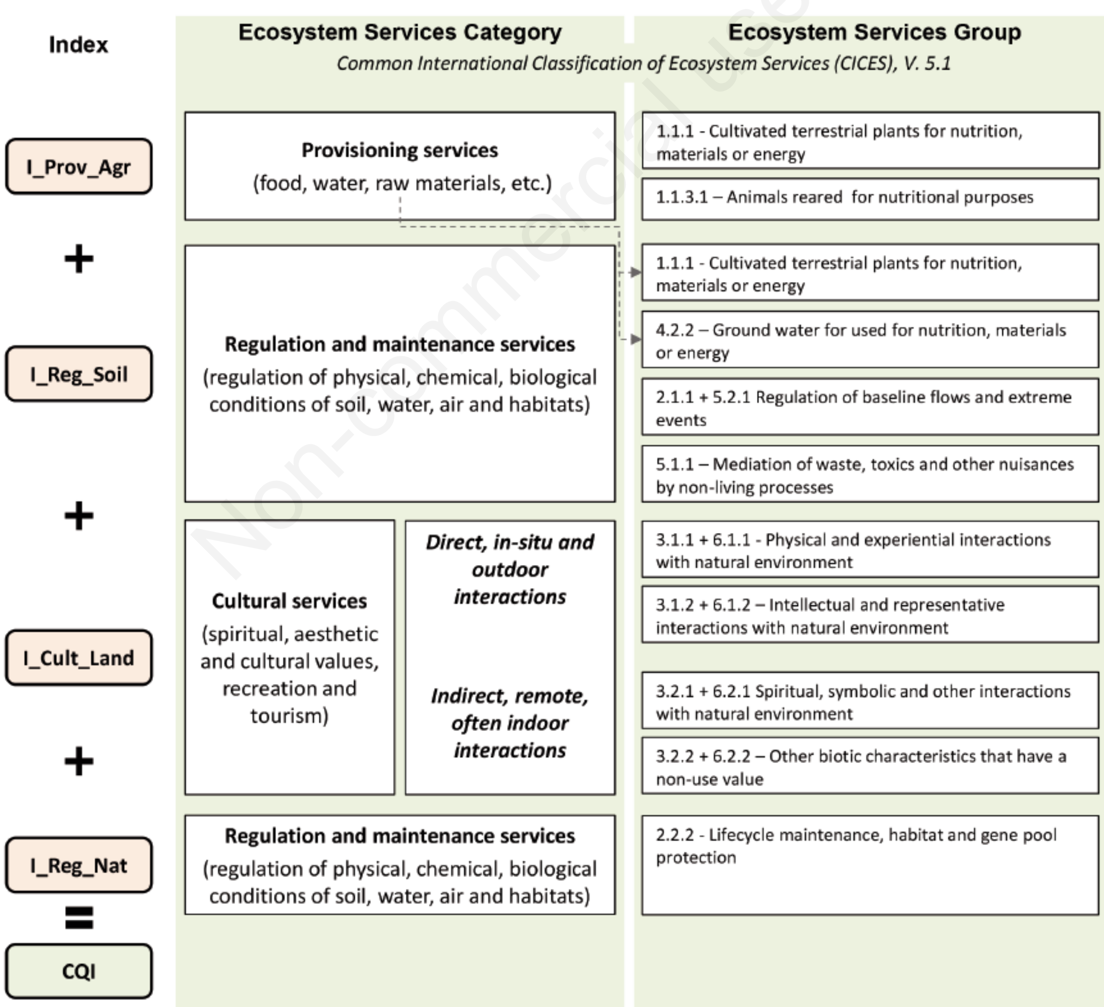


Figure 3. Ecosystem services considered for the index calculation. CQI, composite quality index.

for stormwater infiltration (information coming from a previous study made by the authors (Senes *et al.*, 2021). The ESs provided refer to the following "sections" of the CICES (*Supplementary Table 2*): provisioning (biotic), provisioning (abiotic), regulation & maintenance (biotic), and regulation & maintenance (abiotic).

The categories "A" and "B" are relative to provisioning ESs, but they have been considered in the I_Reg_Soil index because they refer to soil characteristics and their "provisioning" role is "indirect". For the assessment of the regulation ESs related to natural resources (I_Reg_Nat index), a complex set of information derived from different databases has been used: i) natural value of soils, land use (DUSAF), regional parks and protected areas, priority areas for biodiversity, regional ecological network (Lombardy Region); ii) provincial ecological network (province of Monza Brianza); iii) municipal ecological network (municipalities).

The ESs provided refer to the regulation & maintenance (biotic) "section", lifecycle maintenance, habitat, and gene pool protection "group" of the CICES (*Supplementary Table 3*). Finally, for the assessment of the cultural ESs related to the landscape resources (I_Cult_Land index), a complex set of information derived from different databases has been used: i) landscape sensitivity, landscape restrictions, scenic trails, land use (DUSAF) (Lombardy Region); ii) historical gardens, monumental trees, geomorphological and water elements of historical interest, historical and cultural heritage, areas of landscape value (municipalities). The ESs provided refer to the following "sections" of the CICES (*Supplementary Table 4*): cultural (biotic), and cultural (abiotic).

Phase 4: assessment of the provisioning ecosystem services related to the agricultural activity and calculation of the I_Prov_Agr index

The calculation of the index was carried out by assigning a score (*SAgr*), which expresses the intensity and the economic value of the agricultural activity, to different land use classes in non-urbanized territories. *SAgr* (Table 1) is based on the guidelines provided by the Lombardy Region for the "determination of agricultural value to define Strategic agricultural areas" at provincial level (Lombardy Region, 2008) and the Metland planning model (Fabos, 1978). A further score (P_{SIARL}=10) was assigned to cultivated areas belonging to farms included in the SIARL, except for classes with the highest SAgr (Table 1).

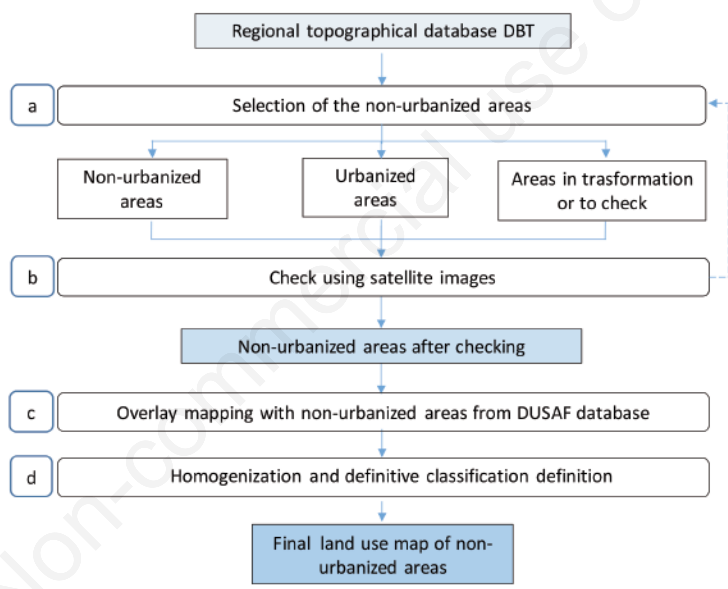


Figure 4. Procedure for the creation of the land use map of non-urbanized areas. DBT, topographical database; DUSAF, agricultural and forestry land use database.

Table 1. Score assigned to land use classes and calculation of the I_Prov_Agr Index.

Land use class	SAgr	P_{SIARL}	S_Agr_{TOT}	I_Prov_Agr
Vineyards, orchards, olive groves	125	0	125	1.00
Horticulture, floriculture, and plant nurseries in greenhouses	110	10	120	0.96
		0	110	0.88
Farms and agricultural production settlements; crops, vegetable gardens, meadows, and chestnuts; horticulture, floriculture, and plant nurseries (not in greenhouses)	100	10	110	0.88
		0	100	0.80
Poplars	90	10	100	0.80
		0	90	0.72
Pastures	75	10	85	0.68
		0	75	0.60
Woods and riparian woods	25	10	35	0.28
		0	25	0.20

SAgr, score related to the intensity and the economic value of the agricultural land-use class; PSIARL, score assigned to the cultivated areas belonging to farms included in the Official Register of agricultural companies of the Lombardy Region.

The final I_Prov_Agr index was calculated on a 0 to 1 scale, with Eq. 1:

$$I\_Prov\_Agr_{[0-1]} = \frac{(SAgr + P_{SIARL})}{125} \quad (1)$$

where: *I_Prov_Agr* is the index that expresses provisioning ESs related to agricultural activity; *SAgr* is the score related to the intensity and the economic value of the agricultural land use class; and P_{SIARL} is the score assigned to the cultivated areas belonging to farms included in the Official Register of agricultural companies of the Lombardy Region (SIARL).

Phase 5: assessment of the regulation ecosystem services related to the soil characteristics and calculation of the I_Reg_Soil index

The index was calculated by assigning a score to each non-urbanized land polygon based on the ESs provided by the soil characteristics. The layers considered for calculation were divided into 4 categories (A, B, C, and D) according to the ESs offered (*Supplementary Table 2*). A specific score was assigned to each layer or class inside the layer (Table 2).

The *A* score was calculated based on the values assigned to each land capability class (Table 3) by the Lombardy Region (2008) and the Metland planning model (Fabos, 1978). Land capability represents a soil characteristic that affects the provisioning (biotic) ESs related to "cultivated terrestrial plants for nutrition, materials or energy" (CICES code 1.1.1). The *A* score was calculated on a 0 to 1 scale with Eq. 2:

$$A_{[0-1]} = \frac{(LC_{[21-100]} - 21)}{(100-21)} \quad (2)$$

where *LC* is the land capability value.

The *B* score was assigned to buffer areas around public wells for drinking water, which are protection zones for groundwater recharge areas to preserve drinking water for human consumption. These areas are fundamental for provisioning (abiotic) ESs related to the supply of "ground water used for nutrition, materials or energy" (CICES code 4.2.2).

The *B* score is equal to 1 (Eq. 3), given the strategic importance of the service provided:

$$B=0 \lor B=1 \quad (3)$$

The *C* score was calculated considering 3 soil characteristics. The first is the "green infrastructure suitability for stormwater management" (*Gsuit*), derived from a previous study by other authors (Senes *et al.*, 2021). This suitability, which identifies the green areas most suitable for the creation of sustainable drainage systems (SuDS), can be effectively used as a measure of "regulation & maintenance – biotic ESs linked to the 'regulation of baseline flows and extreme events" (CICES code 2.2.1). The second characteristic refers to the "geological limitations" (*GeoLim*) of the soils, which are defined by the municipalities based on the geological, hydrogeological, hydraulic, and seismic risks. The territory is divided into classes and subclasses with increasing limitations to land use changes, which can be effectively used to evaluate "regulation & maintenance - abiotic" ESs related to the "regulation of baseline flows and extreme events" (CICES code 5.2.1). They are "implicit" ESs that are provided if the territory is not transformed due to urban development.

The third characteristic refers to the presence of underground cavities in the subsoil (superficial sedimentary deposits) closely related to water infiltration and lithology. It is a well-known characteristic of the Monza Brianza province soils (in Italian known as the *occhi pollini* phenomenon), which is connected not only to the geological and hydrogeological structure but also to the modifications of the underground water circulation produced by human interventions. The real occurrence and location of underground cavities in the subsoil are difficult to map without direct surveys such as penetration tests. For the Monza Brianza province, only the information related to the probability of occurrence of the phe-

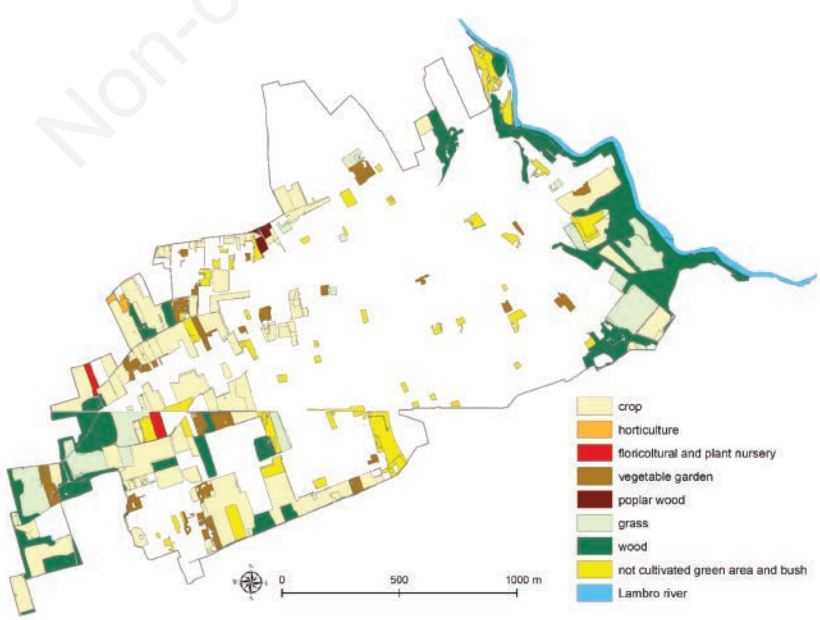


Figure 5. Land use map of non-urbanized areas.

Table 2. Scores assigned to layers (or classes inside the layer) for I_Reg_Soil index calculation.

A Land capability		B Protection zone of wells		C Green infrastructure suitability for stormwater infiltration		Geological limitations		Underground cavities susceptibility		D Soil attitude for spreading livestock slurry		Soil attitude for spreading urban sewage sludge		Soil capacity to surface water protection		Soil capacity to groundwater protection	
class	score	class	score	class	score	class	score	class	score	class	score	class	score	class	score	class	score
I	1.00	yes	1.00	H	1.0	3-4	0-1[c]	H	1.000	H	1.00	H	1.00	H	1.00	H	1.00
II[a]	0.91	no	0.00	H-M	0.8			H-M	0.995	M	0.99	M	0.99	M	0.98	M	0.98
II[b]	0.89			M	0.6			M	0.990	L	0.98	L	0.98	L	0.96	L	0.96
III[a]	0.66			M-L	0.4			M-L	0.985	N	0.96	N	0.96				
III[b]	0.63			L	0.2			L	0.980								
IV[a]	0.53			N	0.0												
IV[b]	0.52																
V-VI[a]	0.34																
V-VI[b]	0.32																
VII[a]	0.03																
VII[b]	0.00																
VIII	0.00																

H, high; M, medium; L, low; [a], 1 soil limitation; [b], 2 soil limitations; [c], score from 0 to 1 assigned to specific classes reported in the municipal plans.

nomenon, the "underground cavities susceptibility" (*SusUC*), is available. As for *GeoLim*, *SusUC* can be effectively used to evaluate "regulation & maintenance - abiotic' ESs related to the "regulation of baseline flows and extreme events" (CICES code 5.2.1).

The *C* score was calculated with Eq. 4:

$$C_{[0\text{-}2]}=(Gsuit_{[0\text{-}1]}+GeoLim_{[0\text{-}1]})\times SusUC_{[0.98\text{-}1]} \quad (4)$$

The *D* score was calculated based on 4 soil characteristics: soil attitude for spreading livestock slurry (*D*1) and urban sewage sludge (*D*2), soil capacity to surface (*D*3), and underground (*D*4) water protection. These characteristics are based on the soil's pedological properties and are determined according to the following parameters such as flooding, slope, groundwater depth, permeability, hydrological group, and granulometry. These characteristics can be effectively used to evaluate "regulation & maintenance - abiotic" ESs related to the "mediation of waste, toxics and other nuisances by non-living processes" (CICES code 5.1.1).

The *D* score was calculated with Eq. 5:

$$D_{[0.84\text{-}1]}=(D1_{[0.96\text{-}1]}+D2_{[0.96\text{-}1]}+D3_{[0.96\text{-}1]}+D4_{[0.96\text{-}1]})\text{-}3 \quad (5)$$

The I_Reg_Soil index was calculated on a 0 to 1 scale based on the criteria indicated below.

Firstly, to protect the most vulnerable areas from urban development, the maximum value (equal to 1) was assigned to the I_Reg_Soil index if any of the following characteristics had the maximum score: land capability (*A*), protection zone of wells (*B*), green infrastructure suitability for stormwater management (*Gsuit*), and geological limitations (*GeoLim*). Therefore, if: *A*=1 then I_Reg_Soil=1; *B*=1 then I_Reg_Soil=1; *Gsuit*=1 then I_Reg_Soil=1; *FeaGeo*=1 then I_Reg_Soil=1.

In all other cases, the I_Reg_Soil index was calculated using Eq. 6:

$$\forall\, A \neq 1, B \neq 1, Gsuit \neq 1, GeoLim \neq 1 \;\Rightarrow\; I\_Reg\_Soil_{[0-1]} = \frac{(A+C)}{2} \times D \quad (2)$$

If the calculated I_Reg_Soil was greater than 1, it was still considered to be 1 (maximum value).

Table 3. Scores assigned to land capability classes.

Land capability class	Land capability value	A score
I	100	1
II[a]	93	0.91
II[b]	91	0.89
III[a]	73	0.66
III[b]	71	0.63
IV[a]	63	0.53
IV[b]	61	0.51
V-VI[a]	48	0.34
V-VI[b]	46	0.32
VII[a]	23	0.03
VII[b]	21	0
VIII	21	0

[a], 1 soil limitation; [b], 2 soil limitations.

Phase 6: assessment of the regulation of ecosystem services related to the natural resources and calculation of the I_Reg_Nat index

To calculate the I_Reg_Nat index, a score was assigned to each polygon of non-urbanized land based on the ESs provided by natural resources. Layers for calculation were divided into the following categories based on the ESs offered: biodiversity protection, naturalistic value of soil, and land use (natural or agricultural) (*Supplementary Table 3*).

The ESs provided by all the considered categories refer to the "regulation & maintenance (biotic)" section, "lifecycle maintenance, habitat, and gene pool protection" group of the CICES (CICES code 2.2.2).

The biodiversity protection category (*BioProt*) includes the layers related to the different types of parks and protected areas, ecological networks (at regional, provincial, and municipal levels), and "priority areas for biodiversity" defined by the Lombardy Region. The scores assigned to each type considered are proportional to the importance of biodiversity protection and the relative level of protection (Table 4).

The second category refers to the "naturalistic value of soils" (*NVS*), which depends on their pedological characteristics. This value can slightly increase the naturalistic quality of a territory and, therefore, has been considered as a "multiplying factor" of the biodiversity protection value (Table 5).

Similarly, land use (*L_Use*) can also represent a "multiplying factor" of the biodiversity protection value. In this case, the score attributed to each land use class, depending on the type (natural or agricultural) of land use/cover, can slightly decrease the naturalistic quality of a territory (Table 5).

If the land use class is neither natural nor agricultural, the assigned score is equal to 0. Therefore, if a biodiversity protection area is characterized by urban land use (by mistake or due to changes that have occurred over time), the territory cannot provide the related ESs (CICES code 2.2.2).

Finally, to ensure the 'natural' land uses are not neglected, if they do not belong to any biodiversity protection area, they have been assigned a score of 0.10.

The I_Reg_Nat index was calculated on a 0 to 1 scale with Eq. 7:

$$I\_Reg\_Nat = \begin{cases} BioProt \times NVS \times L\_Use, & BioProt > 0 \\ 0.1, & BioProt = 0 \wedge L\_Use = 1 \\ 0, & BioProt = 0 \wedge L\_Use \neq 1 \end{cases} \quad (7)$$

If I_Reg_Nat>1, the value is still considered to be 1 (maximum value).

Phase 7: assessment of the cultural ecosystem services related to the landscape resources and calculation of the I_Cult_Land index

The index was calculated by assigning a score to each polygon of non-urbanized land based on the ESs provided by the landscape. The layers considered for calculation are listed in *Supplementary Table 4.* A specific score was assigned to each layer or class within the layer (Table 6). The different landscape characteristics considered can be effectively used to evaluate the biotic and abiotic cultural ESs related to "physical and experiential interactions with natural environment" (CICES codes 3.1.1 and 6.1.1, respectively), "intellectual and representative interactions with natural environment" (CICES codes 3.1.2 and 6.1.2, respectively), and "spiritual, symbolic and other interactions with natural environment" (CICES codes 3.2.1 and 6.2.1, respectively). They can also be used to evaluate the biotic and abiotic cultural ESs related to "characteristics with non-use value" (CICES codes 3.2.2 and 6.2.2, respectively).

The landscape sensitivity (*Land_Sens*) describes the sensitivity of the landscape to territorial transformations and is used to preserve the landscape's peculiarities. Each class has been assigned a score proportional to the level of sensitivity.

Areas subject to landscape restrictions (*Land_Res*), as identified by the regional landscape plan, are characterized by high landscape value (linked to natural and/or historical-cultural components) that is necessary to protect form transformation. Areas subject to landscape restrictions have been assigned a maximum score of 1. Scenic trails (*Sc_Trail*) are linear elements of particular landscape importance due to naturalistic and/or historical-cultural reasons. Areas crossed by scenic trails (buffer of 150 meters) have been assigned a maximum score of 1.

Landscape elements from municipal plans (*LEMP*) represent what municipalities have identified as important landscape resources to be protected. They include i) historical gardens (with the maximum score of 1); ii) monumental trees (with the maximum score of 1); iii) areas of landscape value (with a score of 0.8); iv) other historical and cultural heritage elements (with a score of 0.8); v) water elements of historical interest (with a score of 0.2); vi) geo-morphological elements of historical interest (with a score of 0.2). Finally, some land use classes (*L_Use*) have a landscape value due to natural and/or historical-cultural components that are important to preserve. Each considered class has been assigned a score proportional to the importance and/or the level of contribution to the overall landscape quality.

The I_Cult_Land index was calculated on a 0 to 1 scale by assigning the maximum score of the various layers considered, according to Eq. 8:

Table 4. Biodiversity protection: scores assigned to the different typologies.

Layer	Typology	Score
Protected area and local park	Natura 2000 sites	1.00
Protected area and local park	Priority areas of intervention	1.00
Protected area and local park	Natural parks	0.75
Regional ecological network	Primary elements	0.75
Priority areas for biodiversity	Priority areas for biodiversity	0.75
Regional ecological network	Secondary elements	0.50
Protected area and local park	Regional parks	0.50
Protected area and local park	Local parks	0.25
Regional ecological network	Primary corridors	0.25
Provincial ecological network	Provincial ecological network	0.15
Municipal ecological network	Municipal ecological network	0.15

Table 5. Scores assigned to the soil naturalistic value and land-use classes.

Soil naturalistic value		Land use	
Class	Score	Class	Score
High	1.1	Natural	1.0
Medium	1.0	Agricultural	0.9
Low	1.0	Urban	0.0

I_Cult_Land$_{[0-1]}$=Max(*Land_Sens; Land_Res; Sc_Trail;LEMP;L_Use*) (8)

Phase 8: assessment of the composite quality index for different scenarios

CQI was calculated on a 0 to 1 scale with Eq. 9:

$$CQI_{0-1} = \frac{(W_{AGR} \times I\_Prov\_Agr)+(W_{SOIL} \times I\_Reg\_Soil)+(W_{NAT} \times I\_Reg\_Nat)+(W_{LAND} \times I\_Cult\_Land)}{4} \quad (9)$$

where $W_{AGR[0-1]}$ is the weight of the ESs related to agricultural activity; $W_{SOIL[0-1]}$ is the weight of the Ess related to soil characteristics; $W_{NAT[0-1]}$ is the weight of the ESs related to natural resources; $W_{LAND[0-1]}$ is the weight of the ESs related to landscape resources; $W_{AGR}+W_{SOIL}+W_{NAT}+W_{LAND}=1$.

Since each single index expresses the level of ESs provided, CQI expresses the overall quantity of ESs provided by non-urbanized areas. It is possible to assign a specific weight to each index, based on the importance assumed by each characteristic in the specific context.

As anticipated in the introduction, in the present study authors performed an AHP with the creation of 4 different scenarios to evaluate the possible results of the different importance of the singular indexes eventually assigned by planners and communities involved. The 4 scenarios are the following (Table 7): i) scenario 1, in which the 4 components considered have the same importance; ii) scenario 2, in which soil characteristics are more important than the others; iii) scenario 3, in which natural resources are more important than the others; iv) scenario 4, in which landscape resources more important than the others.

Results and Discussion

The value of each index was calculated for each non-urbanized polygon using the formulas defined in the previous section (Table 8), and the corresponding maps have been generated.

I_Prov_Agr index

Areas with high quality from the agricultural activity perspective (I_Prov_Agr index value greater than 0.6) occupy nearly 61% of the non-urbanized area in the municipality of Sovico (Table 8). These areas (shown in green in Figure 6a) are concentrated in the western part of the municipality, although some can also be found in the Lambro river valley in the eastern part. Additionally, there is a 10% non-urbanized area with no provisioning ESs related to agricultural activities (shown in light blue in Figure 6a) and another 23.5% with a very low capacity (with a value up to 0.2) to provide such ESs (shown in red in Figure 6a).

I_Reg_Soil index

Areas with high quality related to the soil characteristics (I_Reg_Soil index value greater than 0.6) occupy nearly 27% of the non-urbanized area (Table 8). These areas (shown in green in Figure 6b) are concentrated in the eastern part of the municipality (with a high *C* value), although some can also be found in the western part (with a high *A* value). Most of the non-urbanized territory (about 73%) has an I_Reg_Soil value ranging from 0.41 to 0.6 (shown in yellow in Figure 6b), while there are no areas with an index value lower than 0.4.

I_Reg_Nat index

Areas with high quality related to natural resources (I_Reg_Nat index value greater than 0.6) occupy nearly 22% of the non-urbanized territory (Table 8). These areas (shown in green in Figure 6c) are concentrated in the eastern part of the municipality,

Table 6. Scores assigned to layers (or classes inside the layer) for I_Cult_Land index calculation.

Landscape sensitivity		Landscape restrictions		Scenic trails		Landscape elements from municipal plans		Land use	
class	score	class	score	class	score	class	score	class	score
VH	1.0	yes	1.0	yes	1.0	Historical gardens	1.0	Woods	0.8
H	1.0	no	0.0	no	0.0	Monumental trees	1.0	Vineyards	0.6
M	0.2					Areas of landscape value	0.8	Riparian woods	0.4
L	0.0					Historical and cultural heritage	0.8	Wetland vegetation	0.4
VL	0.0					Water elements of historical interest	0.2	Bush with trees	0.4
						Geo-morphological elements of historical interest	0.2	Tree rows	0.4
								Embankment vegetation	0.4
								Beaches and dunes	0.4

VH, very high; H, high; M, medium; L, low; VL, very low.

Table 7. Weights assigned to the indexes in the 4 scenarios.

Index	Scenario 1	Scenario 2	Scenario 3	Scenario 4
I_Prov_Agr	0.250	0.125	0.125	0.125
I_Reg_Soil	0.250	0.625	0.125	0.125
I_Reg_Nat	0.250	0.125	0.625	0.125
I_Cult_Land	0.250	0.125	0.125	0.625
Sum of the weights	**1.000**	**1.000**	**1.000**	**1.000**

in the Lambro river valley. Almost 60% of the non-urbanized area has no regulating ESs related to natural resources (shown in light blue in Figure 6c) or very few (shown in red in Figure 6c). The western part presents an I_Reg_Nat value ranging from 0.21 to 0.4 (shown in orange in Figure 6c).

I_Cult_Land index

Nearly 75% of the non-urbanized area has a great landscape value (I_Cult_Land index greater than 0.6, with more than 70% greater than 0.8) (Table 8). These areas (shown in green in Figure 6d) are concentrated in the eastern and western parts of the municipality. Almost 23% of the non-urbanized area has a very low value of the index (shown in red in Figure 6d) or is equal to 0 (shown in light blue in Figure 6d). These areas are located in the central part of the municipality, close to the urban areas.

Composite quality index map

The calculation of the CQI for the study area led to the creation of 4 maps (one for each scenario), as shown in Figure 7. As can be seen from the maps, the spatial distribution of areas with different

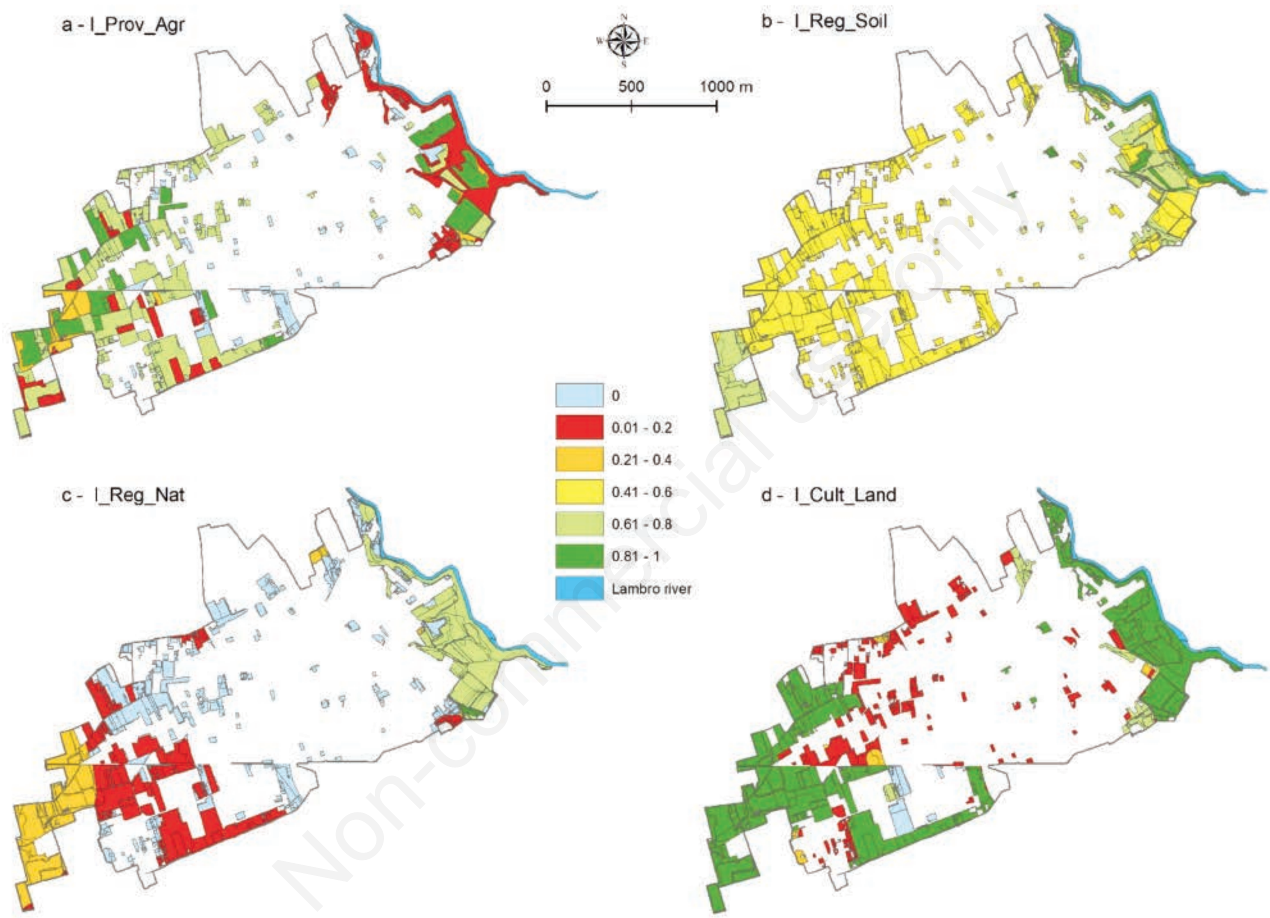


Figure 6. I_Prov_Agr (**a**), I_Reg_Soil (**b**), I_Reg_Nat (**c**), I_Cult_Land (**d**) index map for the municipality of Sovico (Monza Brianza province).

Table 8. Non-urbanized surface (in %) for each value class of each index.

Class value	Non-urbanized surface (in %) for each value class of each index I_Prov_Agr	I_Reg_Soil	I_Reg_Nat	I_Cult_Land
0	10.1%	0.0%	30.7%	3.5%
0.01-0.20	23.5%	0.0%	29.0%	19.3%
0.21-0.40	5.7%	0.0%	17.7%	1.9%
0.41-0.60	0.0%	73.1%	0.4%	0.1%
0.61-0.80	41.7%	19.8%	21.6%	4.8%
0.80-1.00	19.1%	7.1%	0.5%	70.4%
Tot	**100.0%**	**100.0%**	**100.0%**	**100.0%**

CQI within the study area varies greatly depending on the scenario considered.

In scenario 1, light green areas are prevalent (with a CQI class equal to 4) on approximately 45% of the non-urbanized land (Figure 8) and yellow areas (with a CQI class equal to 3) on approximately 29% of the non-urbanized land. In scenario 2, yellow areas (with a CQI class equal to 3) prevail on approximately 67% of the non-urbanized land. In scenario 3, orange areas (with a CQI class equal to 2) prevail on approximately 46% of the non-urbanized land. Finally, in scenario 4, dark green areas (with a CQI class equal to 5) prevail on approximately 47% of the non-urbanized land.

In scenario 2 (where soil characteristics are more important than the other factors), the most represented CQI class is number 3 (with a CQI value of 0.41-0.60), covering almost 67% of the non-urbanized area of the municipality of Sovico. This scenario emphasizes the large presence of areas with medium soil quality (Figure 6b). However, this scenario may give too much importance to areas with poor soil quality compared to the other ESs provided.

In scenario 3 (where regulation ESs related to natural resources are more important than the other factors), the most represented CQI class is number 2 (with a CQI value of 0.21-0.40), covering 46% of the non-urbanized area. In this scenario, the presence of territories in CQI class 1 (with a CQI value of 0.01-0.20) is also significant, while class 5 of CQI is absent. This is consistent with the scarce presence of territories with high-value natural resources (I_Reg_Nat>0.6), concentrated only in the Lambro river valley, and the limited presence of areas with I_Reg_Nat>0.8 (less than 6000 m^2, equivalent to about 0.5% of the non-urbanized areas) (Figure 6c).

As expected, the presence of a large area with I_Cult_Land>0.8 (Figure 6d) determines in scenario 4 (where cultural ESs related to the landscape resources are more important than the others) the presence of almost 50% of non-urbanized areas in CQI class number 5 (with CQI>0.8).

Scenario 1 (where the 4 indexes have the same importance) appears to be the most balanced, showing approximately 45% of the territory in CQI class number 4, approximately 29% in CQI class number 3, approximately 18% in CQI class number 2, and the remaining divided between CQI class numbers 1 and 5. From a planning perspective, it is crucial to identify areas that can provide more ESs, both in terms of quantity and type. To identify such areas (*i.e.*, those of higher overall quality), we analyzed the 4 scenarios simultaneously, firstly by identifying and quantifying areas with all the indicators (I_Prov_Agr, I_Reg_Soil, I_Reg_Nat, and I_Cult_Land) in class 4 or 5 (*i.e.*, with a value >0.6) in all 4 scenarios (Table 9), and secondly, those with indicator values in class 3 (*i.e.*, with a value >0.4) but with at least one indicator with a value in class 5 (Table 9). We also verified the CQI class of these Only about 5% of the non-urbanized territory (approximately

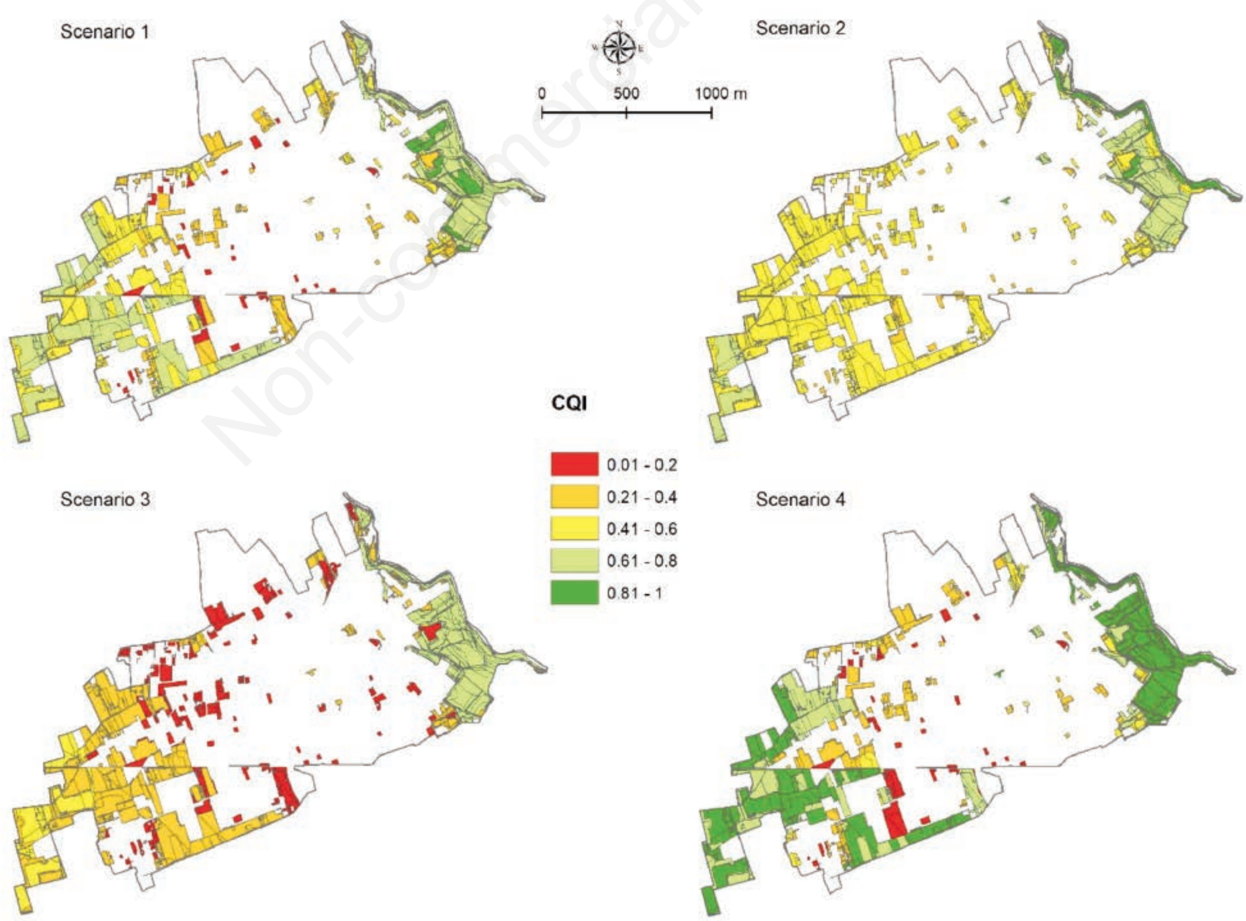
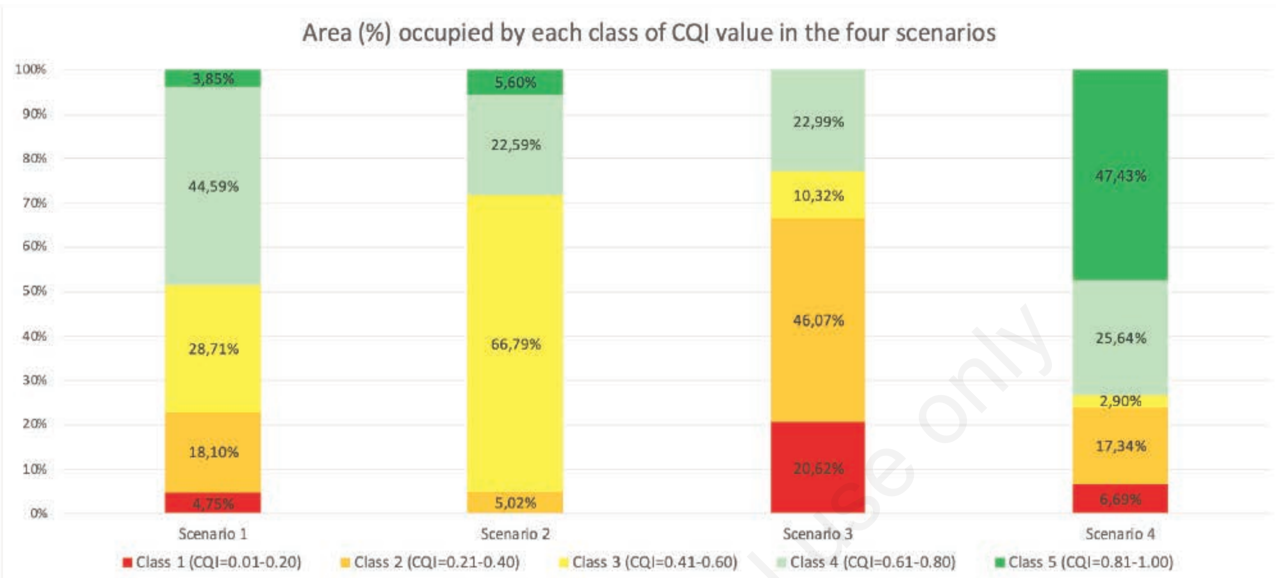


Figure 7. Maps of the composite quality index for the 4 scenarios. CQI, composite quality index.).

55,000 m^2) has all indicators with a value greater than 0.6 (*i.e.*, in class 4 or 5) in all scenarios. This percentage increases to just over 8% (approximately 93,000 m^2) if we also consider areas with index values in class 3 but with at least one index in class 5. This 8% of non-urbanized territory represents the part with the highest quality, capable of providing more ESs regardless of the scenario considered (Figure 9). To better evaluate the remaining 92% of the non-urbanized territory, we analyzed the presence of the highest CQI classes (4 and 5) in the various scenarios to extrapolate the location and extent of areas with higher quality regardless of the scenario considered (*i.e.*, regardless of the relative importance of the ESs provided).



CQI Value		Area (%) occupied by each class of CQI Value			
Class	Interval	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Class 5	0.81-1.00	3.85%	5.60%	0,00%	47.43%
Class 4	0.61-0.80	44.59%	22.59%	22.99%	25.64%
Class 3	0.41-0.60	28.71%	66.79%	10.32%	2.90%
Class 2	0.21-0.40	18.10%	5.02%	46.07%	17.34%
Class 1	0.01-0.20	4.75%	0,00%	20.62%	6.69%

Figure 8. Synthesis of the areas (%) occupied by each class of composite quality index value in the 4 scenarios. CQI, composite quality index.

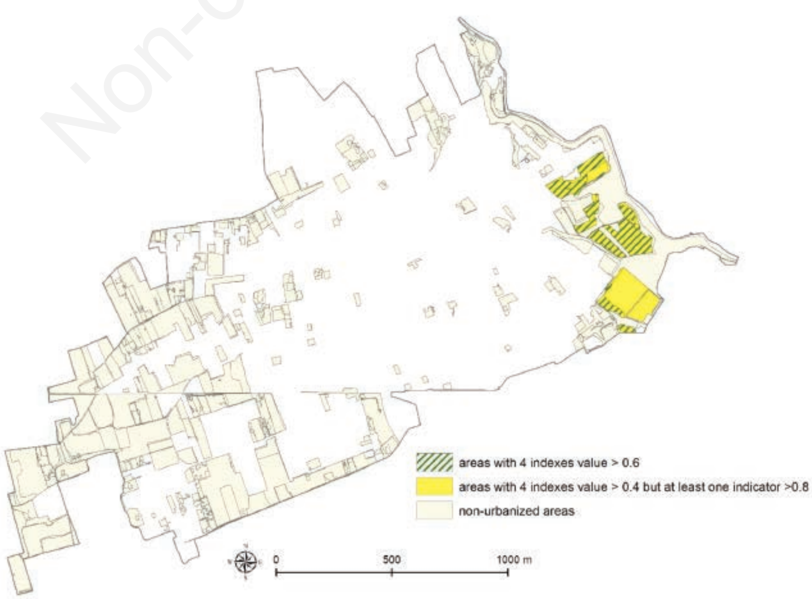


Figure 9. Not urbanized areas with the 4 indexes (I_Prov_Agr, I_Reg_Soil, I_Reg_Nat, I_Cult_Land) values >0.6 (*i.e.*, in class 4 or 5) in all scenarios, or with the indexes values also in class 3 (*i.e.*, with a value >0.4) but with at least one index in class 5 (*i.e.*, with a value >0.8).

The analysis showed that the study area comprises 90,001 m^2 of territory (about 8%) with CQI in class 5 (*i.e.*, CQI>0.8) in 2 or 3 scenarios, and 429,616 m^2 (about 39%) with CQI in class 5 in at least one scenario (Table 10). These areas, which occupy approximately 47% of the non-urbanized territory of the study area, provide a large number of ESs in practically all scenarios and are concentrated in the eastern part of the municipality (Lambro river valley) and in the west (Figure 10).

The assessment of the data obtained from the application of the methodology to the study area indicates that Scenario 1, based on the equal importance of all aspects considered and the relative ESs provided, offers the most adequate interpretation of the quality of

Table 9. Different combinations (and relative area) of non-urbanized territories with the values of all indexes in class 4 or 5 (*i.e.*, with a value >0.6) in all scenarios, or with the indexes values also in class 3 (*i.e.*, with a value >0.4) but with at least one index in class 5, and the relative composite quality index class.

I_Prov_Agr Class	I_Reg_Soil Class	I_Reg_Nat Class	I_Cult_Land Class	CQI (Composite Quality Index) class				Area	
				Scenario 1	Scenario 2	Scenario 3	Scenario 4	m^2	%
5	4	4	5	5	4	4	5	34,533	3.09%
4	5	4	5	5	5	4	5	6,752	0.60%
4	4	4	5	4	4	4	5	6,353	0.57%
5	4	4	5	4	4	4	5	5,687	0.51%
4	4	4	5	5	4	4	5	1,734	0.16%
Total								**55,059**	**4.93%**
5	3	4	5	4	4	4	5	25,243	2.26%
4	3	4	5	4	4	4	5	10,533	0.94%
5	4	3	5	4	4	4	5	1,152	0.10%
5	3	4	5	4	3	4	5	564	0.05%
4	3	3	5	4	3	3	5	318	0.03%
5	3	3	5	4	3	3	5	242	0.02%
4	5	3	5	4	4	4	5	162	0.01%
Total								38,214	3.41%
Overall Total								**93,273**	**8.34%**

Figure 10. Synthesis of the composite quality index values in the different scenarios. CQI, composite quality index.

the non-urbanized territory. The analysis of the distribution of areas with the highest quality, those with CQI>0.6 in at least one scenario (the green areas in Figure 10) in the different scenarios shows that (Table 11): i) scenario 2 presents a high percentage (48.4%) of areas with CQI in class 2 and 3; ii) scenario 3 presents 56.4% of areas with CQI in classes 2 and 3; iii) scenario 4 presents 99.9% of areas with CQI in class 5 in at least one scenario, which seems to be an overestimation of the contribution of cultural ESs related to landscape resources; iv) scenario 1 presents 8.3% of areas with CQI in classes 5 in 2 or 3 scenarios and 91.7% with CQI in class 4 in at least one scenario. This scenario is able to assess areas with the highest quality without overestimating any of the indexes considered.

Conclusions

The quality of non-urbanized territories is a crucial factor that must be considered when managing the phenomenon of land take. The goal should be not only to reduce the quantity of land taken but also to preserve the territories with higher quality, which are capable of providing more ESs, in terms of both quantity and typology. The proposed procedure, applied in the study, allows to identify the different ESs provided by territories, considering several characteristics, and assess them through the calculation of specific indicators using GIS. The method was applied to the municipalities of the province of Monza Brianza, using official geographical data available from regional, provincial, and municipal databases. This implies that expensive ground surveys or the implementation of a new set of data are not required.

The findings of the study provide useful information to planners to guide decisions regarding future land use more sustainably, safeguarding high-quality territories from land take.

The proposed assessment methodology can be applied to territories with different characteristics (*e.g.*, lowland rather than mountain areas) by identifying the most appropriate layers to be used for calculating the indexes.

The creation of scenarios allows for a more in-depth analysis, identifying areas with higher quality in different scenarios and considering the relative importance of the characteristics for a specific territorial context.

The study also revealed some limitations, linked to the possi-

Table 10. Distribution of the composite quality index classes in the different scenarios (and relative areas occupied).

CQI (Composite Quality Index)	Area		Number of scenarios with CQI in class					Area	
	m^2	%	Class 5	Class 4	Class 3	Class 2	Class 1	m^2	%
CQI in class 5 in 2 or 3 scenarios	90,001	8.17%	3	1				6,820	0.62%
			2	2				82,263	7.47%
			2	1		1		917	0.08%
CQI in class 5 in 1 scenario	429,616	39.01%	1	3				113,912	10.34%
			1	2	1			82,320	7.47%
			1	2		1		5,196	0.47%
			1	1	2			53,679	4.87%
			1	1	1	1		174,509	15.84%
CQI in class 4 in at least 1 scenario (no areas in class 5)	297,872	27.04%		4				2,450	0.22%
				3	1			15,040	1.37%
				2	2			922	0.08%
				2	1	1		14,520	1.32%
				1	3			2,357	0.21%
				1	2	1		225,712	20.49%
				1	1	2		71	0.01%
				1	1	1	1	36,801	3.34%
CQI in class 3 in at least 1 scenario (no areas in class 4 or 5)	230,969	20.97%			3	1		18,196	1.65%
					2	2		59,809	5.43%
					2	1	1	15,563	1.41%
					1	2	1	136,121	12.36%
					1	1	2	1,279	0.12%
CQI in class 2 in at least 1 scenario (no areas in class 3 or 4 or 5)	52,970	4.81%				3	1	550	0.05%
						1	3	52,420	4.76%

Table 11. Distribution of the areas with the highest quality (with composite quality index in class 5, *i.e.*, >0.8, in at least one scenario), in each of the 4 scenarios considered.

Scenario	Class		Area with CQI (Composite Quality Index) in class 5			
			in 2 or 3 scenarios	in 1 scenario	Total	
Scenario 1	Class 5	m^2	43,116	0	43,116	
		%	8.3%	0.0%	8.3%	519,617 m^2
	Class 4	m^2	46,885	429,616	476,501	(100.0%)
		%	9.0%	82.7%	91.7%	
	Class 2 and 3	m^2	0	0	0	0 m^2
		%	0.0%	0.0%	0.0%	(0.0%)
Scenario 2	Class 5	m^2	53,705	662	54,367	
		%	10.3%	0.1%	10.5%	268,161 m^2
	Class 4	m^2	36,296	177,498	213,794	51.6%
		%	7.0%	34.2%	41.1%	
	Class 2 and 3	m^2	0	21,456	0	251,456 m^2
		%	0.0%	48.4%	0.0%	48.4%
Scenario 3	Class 5	m^2	0	0	0	
		%	0.0%	0.0%	0.0%	226,676 m^2
	Class 4	m^2	89,083	137,593	226,676	43.6%
		%	17.1%	26.5%	43.6%	
	Class 2 and 3	m^2	9,178	292,023	0	292,941 m^2
		%	0.2%	56.2%	0.0%	56.4%
Scenario 4	Class 5	m^2	90,001	428,954	518,954	
		%	17.3%	82.6%	99.99%	519,204 m^2
	Class 4	m^2	0	249	249	99.9%
		%	0.0%	0.0%	0.0%	
	Class 2 and 3	m^2	0	413	0	413 m^2
		%	0.0%	0.1%	0.0%	0.1%

CQI, composite quality index.

ble overestimation of one index compared to the others (in the case of the presented application, the I_Cult_Land index). In this sense, it could be useful in the future to conduct a sensitivity analysis linked to the values attributed to the individual indexes.

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Supplementary material:

Supplementary Table 1. Ecosystem services and layers used for I_Prov_Agr calculation.

Supplementary Table 2. Ecosystem services and layers used for I_Reg_Soil calculation.

Supplementary Table 3. Ecosystem services and layers used for I_Reg_Nat calculation.

Supplementary Table 4. Ecosystem services and layers used for I_Cult_Land calculation.