Definition of a land quality index to preserve the best territories from future land take. An application to a study area in Lombardy (Italy)

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Abstract

Land take is a process of land-use change in which the agricultural and natural land is taken by residential, industrial, infrastructure and other developments. This change causes the loss of a non-renewable resource, such as the agricultural/natural soil, and the relative natural, cultural and landscape resources.

The growing awareness about the loss of ecosystem services related to land take led developed countries to try to reduce the quantity of land taken with new laws and regulations. The European Union has set the goal of zero land take by 2050. It is not only a problem of limiting and slowing down the phenomenon, but it is always clearer that the quality of the land taken has to be assessed and adequately considered during the land-use planning process. In fact, in some cases like in the Lombardy Region, the law focuses not only on reducing the amount of land take, but also on limiting the loss of land with *high qualities*, requiring municipalities to assess the productive, naturalistic and landscape qualities of the territory. In this paper, the authors develop, using the geographical information system technology, a methodology to define and calculate a composite land quality index (LQI). The methodology has been applied to a case study in the Lombardy region and has allowed to assess the quality of the territory in a rigorous and transparent way using available official data. In order to take into account the relative importance that stakeholders and land-use planners can give to the different components of LQI, analytic hierarchy process has been performed ad 4 different scenarios have been developed. LQI can support the land-use planning process in an *ex-ante* evaluation of different transformations hypotheses and in the definition of *quality-based* quantitative thresholds and monitoring of their trend over the time.

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Introduction

The irreversible conversion of agricultural and natural soils into urban ones causes, in the industrialized countries, alterations of the hydro-geological conditions for excessive soil sealing and a progressive environmental degradation, with a consequent interruption of the biological flows. 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, 2010).

Land take has a negative impact on the territory, causing structural and functional disorders, landscape degradation, increased fragility of environmental systems and a loss of biodiversity (Diti *et al.*, 2015). In recent decades, there has been a significant increase of these processes of soil quantity and quality loss (European Environmental Agency, 2019), and it is simple to imagine that, without appropriate policies, they will continue to increase (Tassinari *et al.*, 2013).

Land take is closely linked to urban sprawl; urban sprawl designates land consuming urban development, which can take the form of either low density or dispersed development – or both combined.

Land take does not always coincide with urban sprawl, since it can occur outside of urban or peri-urban areas and new urban development causing land take is not necessarily sprawled: it can be developed at high density, mixed use, with a compact urban form. Yet excessive land take is a direct consequence of low-density development, which means the main channel to tackle land take is to minimize urban sprawl.

Land take is a global phenomenon (see Colsaet *et al.*, 2019, for a systematic review), both in the developed and the developing countries. With worldwide population increasing and the growth of urban areas, future urbanization will continue at an unprecedented rate. Moreover, urban land expansion is generally growing at faster rates than urban population, suggesting that urban growth is becoming more dispersed than compact. A much faster relative increase in land take than that of demographic growth has been observed in different regions of the world, such as in Europe where land take can even occur alongside declining population (Decoville and Schneider, 2015).

The most commonly used data set in intra-European land cover comparisons comes from the Corine Land Cover (CLC) project directed by the European Environment Agency. It is a project based on the processing of satellite images. According to CLC project, 1000 km^2 of land has been artificialized between 1990 and 2000 each year in Europe, 920 km^2 between 2000 and 2006, 770 km^2 between 2006 and 2012, and 440 km^2 between 2012 and 2018 (European Environmental Agency, 2019).

The land take in Italy continues too: about 50 km^2 of land has been artificialized between 2015-2018 each year (47.8 km^2

between 2015-2016, 50.8 km^2 between 2016-2017 and 48.1 km^2 between 2017-2018) (ISPRA, 2018). Comparing land take between Italian regions is problematic because different regions use different data source and different criteria to measure increment (% on total area or % on built area, for example) (CRCS, 2018). Furthermore, the need to measure not only the quantity of the land take, but also the quality of the land taken represents a hard challenge (Ronchi *et al.*, 2019).

Lombardy is the Italian region with the highest percentage of urban areas (ISPRA, 2018), about 15% (Regione Lombardia, 2017). From 1955 to 2012 the urbanized areas have increased from 4% to 15% (from about 1000 km^2 to about 3500 km^2) of the regional surface, with a reduction of the agricultural areas from 57% (about 13,200 km^2) to 44% (about 10,250 km^2). This increase has been often indifferent to the effective housing needs and not connected to the real demographic changes.

The growing awareness about the consumption of a non-renewable resource led the most part of developed countries to try to face the problem with new laws and regulations. The European Union has set the goal of zero land take by 2050 (European Commission, 2016).

According with these programmatic documents, the strategies to limit land take can be different: i) imposition of thresholds and regulations aiming to limit new losses; ii) mitigation measures for new constructions; iii) compensation measures made to balance an already occurred loss; iv) urban regeneration and policies for the reuse of buildings.

According with Grădinaru (Grădinaru *et al.* 2019), land abandonment in urban areas is the result of both local and regional/national scales forces. Local drivers include: poor functioning of the local land market, lack of adaptation of urban planning to socio-economic changes, changes in zoning decisions, land parcel characteristics, such as scattered locations and inconvenient shape. Some other drivers affect land abandonment indirectly, and are mostly linked to economic, institutional, and social aspects working at regional or national scale: ineffective agricultural and trade policy, jobs shifting from agriculture to the second and third sectors. For these reasons, the strategy iv) is the most sustainable solution in the long term: only systematically giving new life and new functions to obsolete or abandoned areas, it is possible to obtain the zero-land take (European Commission, 2016).

Italy has four levels of government: national, regional and local. Land-use planning system follows a model like that of federal countries, with regional laws and regulations as the main source of legal provisions with regards to planning process.

Italy has a three-tier hierarchical planning system. At the regional level, *Regional Territorial Plan* identifies general policy priorities and objectives at the regional level and *Regional Landscape Plan* provides strategies to preserve and enhance the landscape. *Provincial Territorial Coordination Plans* aim to coordinate municipal land-use decisions within province. *Local Development Plan* is the main statutory land-use plans developed by municipalities (OECD, 2017).

Given the absence of a national framework law, (provided for in the Constitution but never approved by parliament) regional provisions can vary from each other. Regarding land take, several Regions have included the reduction of land take among the criteria that should guide the land use changes and landscape transformations. Some Regions have approved specific legislations (eleven Regions, including Lombardy), other have initiated partial reviews of existing laws, and others have not yet advanced legislative proposals.

Lombardy region, with the Law n. 31/2014, tries to tackle the problem of land take. According to this law, land take is the transformation, for the first time, of an agro-forestry-pastoral-natural area in an urbanized one. Land take is calculated, at municipal level, as the increase (%) of urbanized area (as provided by the land-use plan) respect to the actual urbanized area. The result of this approach is that the highest land take occurs in less urbanized areas, while in the most urbanized areas (*e.g.* big cities) the % of new urban areas is obviously less and, therefore, the land take seems less important (even if in absolute terms the hectares of new urbanized areas are more). In this way, Lombardy tries to better protect the territories that retain large not urbanized areas. The law identifies different homogeneous areas in which apply different thresholds of land take reduction in the next years.

For the application of this law, the Lombard municipalities must produce a *land quality map* (with reference to the agricultural, naturalistic and landscape peculiarities), in order to preserve the most valuable parts of their territory from the future land take. In this way, municipalities are requested to adopt land-use plans that reduce the land take, considering not only the quantitative but also the qualitative aspects (Senes and Cirone, 2018).

The goal of the present work was to develop a methodology useful to define and calculate a composite land quality index (LQI). The methodology has been applied to a Lombard case study in order to verify its capability to be used at municipal level.

Materials and methods

The quality of non-urbanized territories is not easy to define: in recent decades we have moved from a vision in which the quality of the agro-silvo-pastoral territory was expressed almost exclusively by its productive capability, to a more holistic vision, in which the non-urbanized territory is the bearer of a diverse range of values, which are expressed through its ability to provide a plurality of ecosystem services (Vizzari and Sigura, 2015). This plurality of services offered (which, therefore, expresses the quality of a given territory) refers to three broad categories, as defined by the Common International Classification of Ecosystem Services (CICES), developed from the work on environmental accounting undertaken by the European Environmental Agency (EEA) (Haines-Young and Potschin, 2018): i) provisioning services (food, water, raw materials, *etc.*); ii) regulation and maintenance services (regulation of physical, chemical, biological conditions of soil, water, air and habitats); iii) cultural services (spiritual, aesthetic and cultural values, recreation and tourism).

According to this evolutionary framework, the Lombardy regional law on land take establishes that municipalities have to produce a *quality map* of their not urbanized territory and specifically defines that the *quality* must refer to the *agricultural, naturalistic and landscape peculiarities* (Regione Lombardia, 2014).

Definition of the methodology

The methodology developed is divided into the following stages: i) definition of the information needed; ii) analysis of the available data and data selection; iii) definition of the procedure for the calculation of the LQI.

Definition of the information needed

The information to be used, must be: official, available (to avoid specific surveys by municipalities), homogeneous (at least at the regional level, in order to allow comparison between various areas), with appropriate level of detail (scale), available in numeric format [in order to be managed *via* geographical information system (GIS)].

Analysis of the available data and data selection

Official and public databases have to be analyzed and available data have to be classified by thematic area. The data have to be reviewed in order to make a selection, not considering the data less reliable and avoiding possible duplication. Moreover, the data to be privileged are those readily available, effectively classified and easily interpretable, updated and with the appropriate level of spatial resolution and descriptive details.

Table 1 summarizes the thematic layers used for the application of the procedure. Most of the databases comes from Lombardy Region with a scale of 1:10,000 (consistent with the objectives of the study); some themes concerning soils characteristics are at 1:25,000 scale. The update of the data is good, between 2011 and 2015.

Definition of the procedure for the calculation of the land quality index

The procedure has to be based on the available data and on the GIS capabilities. The characteristics of the territory have to be classified and scored, calculating an index on a 0-1 scale. Then, using the GIS overlay mapping capabilities, a composite quality index has to be calculated.

According to CICES Ecosystem Services Classification (Haines-Young and Potschin, 2018) and to the territorial quality aspects expressed by the Lombardy Region (Regione Lombardia, 2014), we defined the conceptual model reported in Figure 1 with four indexes to be calculated on a 0-1 scale: i) the pedological index (IPed), expressing the pedological value of the soil and its capacity in protecting groundwater, but also taking into account eventual limitations; ii) the naturalistic index (INat), expressing the naturalistic qualities of the territory and the sensitivity of the natural resources to land use changes; iii) the landscape index (ILand), expressing the landscape qualities and its landscape sensitivity to land use changes; iv) the agricultural use index (IAgr), expressing the productive quality of the agricultural land.

The four indices were finally aggregated in order to obtain a composite LQI, in order to produce a *land quality map* useful to preserve the most valuable parts of the territory from the future land take.

Application to a case study

The methodology developed has been applied to a case study in Lombardy region, in order to better define and validate the procedures. The method has been defined for an application at the

Table 1. Thematic layers selected for the application of the methodology.

Layer	Origin	Scale	Year	Area covered
Pedological quality				
Land Capability (Soil Map)	Lombardy Geoportal	25000	2013	Region - Plain
Soil Attitude for Spreading Slurry	Lombardy Geoportal	25000	2013	Region - Plain
Soil Capacity to Groundwater Protection	Lombardy Geoportal	25000	2013	Region - Plain
Geological Limitations	Lombardy Geoportal	25000	2013	Region
Landslide Areas	Lombardy Geoportal	10000	2007	Region
Flood Risk Areas	Lombardy Geoportal	25000	2015	Region
Wells	Brescia Province Geoportal	10000	2014	Brescia Province
Water Catchment Points	Lombardy Geoportal	10000	2013	Region
Hydro-geological Risk	Lombardy Geoportal	10000	2015	Region
River Buffer Areas	Lombardy Geoportal	10000	2015	Region
Naturalistic quality				
Soil Naturalistic Value	Lombardy Geoportal	25000	2013	Region - Plain
Ecological Network	Lombardy Geoportal	10000	2009	Region
Monumental Trees	Brescia Province Geoportal	10000	2014	Brescia Province
Protection Zone	Lombardy Geoportal	10000	2014	Region
Woods	Brescia Province Geoportal	10000	2012	Brescia Province
Natural Parks	Lombardy Geoportal	10000	2015	Region
Fontanili (Lowland Springs)	Lombardy Geoportal	10000	2013	Region
Landscape quality				
Landscape Sensibility	Lombardy Geoportal	10000	2011	Region
Landscape Limitations	Lombardy Geoportal	10000	2014	Region
Places of Landscape Significances	Brescia Province Geoportal	10000	2014	Brescia Province
Archeological Sites	Brescia Province Geoportal	10000	2014	Brescia Province
Cultural Heritage	Lombardy Geoportal	10000	2011	Region
Agricultural use				
Land Use	Lombardy Geoportal	10000	2012	Region

municipal level, using 1:10,000 scale and minimum mapping unit equal to 1600 m^2 (4×4 mm at 1:10,000 scale).

The study area is the municipality of Passirano, in the Province of Brescia (Figure 2), a small village (about 7000 inhabitants in 13.5 km^2) in the Franciacorta, the hilly area, famous for its viticulture, located west of the city of Brescia and south of the Iseo Lake.

The data used, coming from official databases of the Lombardy Region, have been processed using ESRI ArcGIS software. Table 1 summarizes the thematic layers used for the application of the procedure.

Pedological index

The index has been calculated taking into account the pedological value (PV) and soil weakness (W) of the territory.

The PV has been calculated combining the information related to the land capability (LC), the soil attitude to spreading of slurry (SL) and the soil capacity to groundwater protection (PROT).

LC is calculated with the following formula:

$$LC_{[21-125]} = [(Cl_i\_Sc_{[25-125]} + Limit_i1\_Sc_{[-2;0]} + Limit_i2\_Sc_{[-2;0]}) \quad (1)$$

where:

LC = total land capability score, that can range from 21 to 125;

Cl_i_Sc = score of the *i-th* land capability class, that can range from 25 to 125 (Table 2);

$Limit_i1\_Sc$ = score of the first limitation of the i-th and capability class, that, if present, can subtract 2 points to LC;

$Limit_i2\_Sc$ = score of the second limitation of the i-th and capability class that, if present, can subtract other 2 points to LC.

The procedure used to assign Cl_Sc score to each land capability class (Table 2) refers to the Metropolitan landscape planning model (Metland) (Fabos, 1978).

SL and the PROT are *correction factors* of LC, ranging from 0.98 to 1 (if there is no correction) (Table 2).

The final value of PV, on a 0-1 scale, is calculate with the following formula:

$$PV = \frac{(LC_{[21-125]} x SL_{[0.98-1]} x PROT_{[0.98-1]}) - 20.1684}{125 - 20.1684} \quad (2)$$

where *20.1684* is the lowest possible value of PV.

The soil weakness (W) has been derived combining the information related to the existence of geological limitations, landslide areas, flood risk areas, wells and water catchment points respect areas, hydro-geological risk areas, and rivers buffers. The soil weakness (W) is equal to "1" when one or more of these limitations are present. If no limitation is present, W is equal to "0".

The presence of limitations is not a pedological *quality* but determines the necessity to protect these areas from possible future urbanization. For this reason, in the following formula, areas with

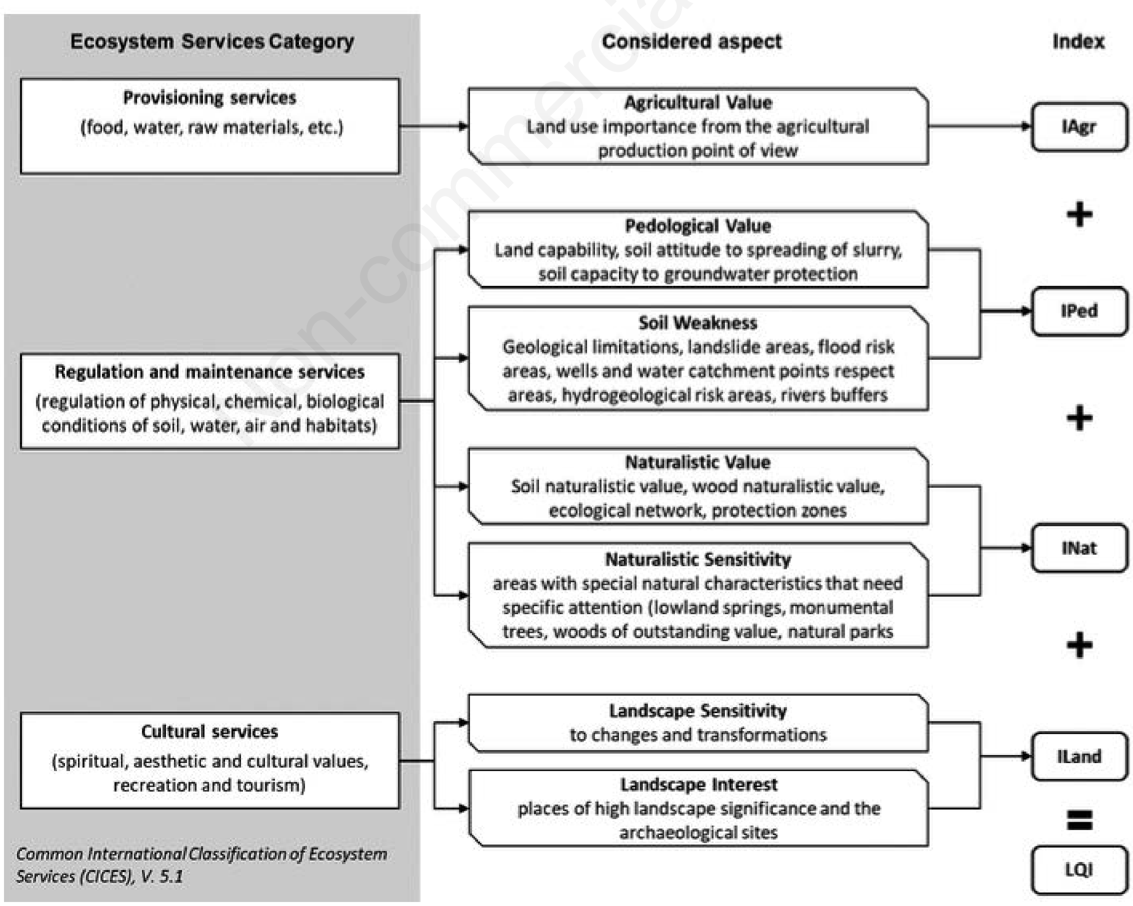


Figure 1. Conceptual model developed to calculate the land quality index (LQI).

W = 1 have been considered of *particular value*, to be excluded from any changes in land use/land cover (LULC), and so determining an IPed = 1, independently from the PV value.

The final value of IPed is calculated with the formula:

$$IPed_{[0-1]} = PV_{[0-1]} + W_{[0;1]} \quad \text{with} \quad IPed_{[0-1]} = \begin{cases} PV if W = 0 \\ W if W = 1 \end{cases} \qquad (3)$$

Naturalistic index

The naturalistic index (INat) has been calculated taking into account the naturalistic value (NV) and the naturalistic sensitivity (NS).

NV is obtained combining the information related to the *soil* naturalistic value (SNV), to the *wood* naturalistic value (WNV), to the presence of the ecological network (EN) and protection zones (PZ).

The SNV score (Table 2) indicates how much that soil is valuable from the naturalistic point of view.

The WNV score (Table 2) indicates the importance of the woods from the naturalistic point of view. It has been calculated based on the *compensation rate* defined by the Environmental laws in case of conversion of woods in other uses, ranging from 1:5 (5 hectares of new woods for each hectare of destroyed wood) to 1:1.

The EN score (Table 2) indicates the presence of elements of the primary or secondary ecological network, existing and planned at regional and local level.

The PZ score is “1” in the protection zones derived from provincial general plans, and “0” in the other areas.

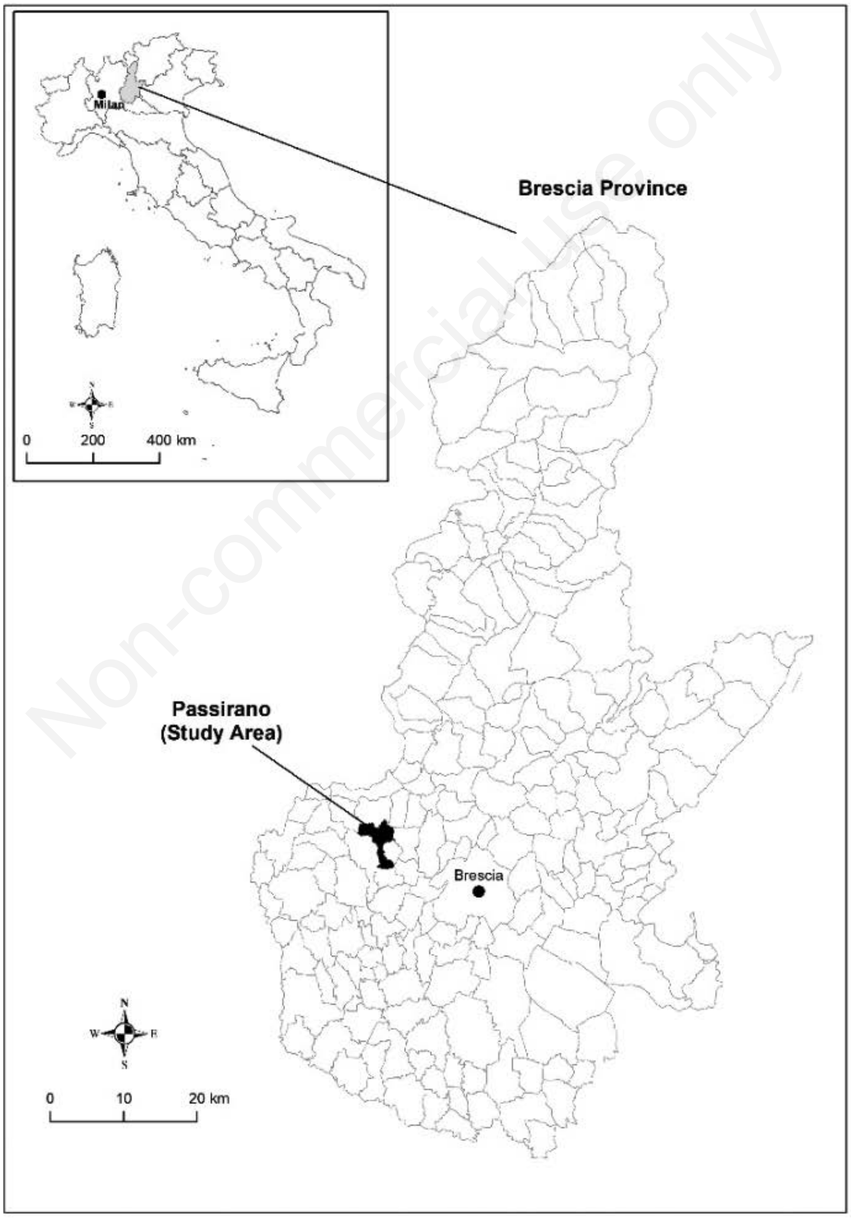


Figure 2. Location of the study area (municipality of Passirano, Province of Brescia).

The final value of NV, on a 0-1 scale, is calculated with the following formula:

$$NV_{[0-1]} = \frac{(SNV+WNV+EN+PZ)}{4} \quad (4)$$

NS is linked to the presence of areas with special natural characteristics that need specific attention, such as *fontanili* (typical lowland springs of the Po valley), monumental trees, woods of outstanding value (not transformable by law) and natural parks. Areas with the presence of at least one of these features have a NS value equal to “1”; NS value is equal to “0” in the other areas.

The final value of INat is calculated with the following formula:

$$INat_{[0-1]} = NV_{[0-1]} + NS_{[0;1]} \text{ with } INat_{[0-1]} = \begin{cases} NV if NS = 0 \\ NS if NS = 1 \end{cases} \quad (5)$$

Areas with NS = 1 are considered so important from the naturalistic point of view to determine the value (= 1) of the whole INat.

Landscape index

The landscape index (ILand) has been calculated taking into account the landscape sensitivity (LS) and the landscape interest (LI).

Table 2. Scores assigned to the classes of the different layers considered in the application.

Index	Thematic layer	Class	Score
IPed			Cl_Sc
	Land capability (LC)	I	100 (125*)
	** Cl_Sc score has been increased by 25*	II	95 (120*)
	if the agricultural land-use has	III	75 (100*)
	particular economic value (such as in the	IV	65 (90*)
	case of orchards and vineyards)	V	50 (75*)
		VI-VII-VIII	25 (50*)
	Soil attitude for spreading of slurry (SL)	Soils suitable without limitations	1
		Soils suitable with slight limitations	0.995
		Soils suitable with medium limitations	0.99
		Soils not suitable	0.98
INat	Soil capacity groundwater protection (PROT)	High	1
		Medium-high	0.995
		Medium	0.99
		Medium-low	0.985
		Low	0.98
	Soil Naturalistic Value	High	1
		High-moderate	0.9
		High-low	0.8
		Moderate	0.5
		Moderate-low	0.3
		Low	0
	Wood Naturalistic Value (WNV)	Compensation rate	WNV
		01:05	1
		01:04	0.8
		01:03	0.6
		01:02	0.4
		01:01	0.2
		No woods	0
	Ecological Network (EN)	Primary	1
		Secondary	0.5
		No elements	0
ILand	Landscape Sensitivity (LS)	Very high	1
		High	0.75
		Medium	0.5
		Low	0.25
		Very low	0
IAgr	LULC	Orchards and vineyards	125
		Arable land, meadows and pastures	100
		Agricultural wood and poplars	90
		Woods	75
		Shrubs	50
		Abandoned agricultural areas	25
		Urbanized areas	0

IPed, pedological index; INat, naturalistic index; ILand, landscape index; IAgr, agricultural use index.

LS expresses the sensitivity of the landscape to changes and transformations, taking into account morphological-structural aspects, symbolic value and the presence of outstanding views. The territory is divided into 5 classes with a value ranging from "0" to "1" (Table 2), following the indication of the Lombardy Region (Regione Lombardia, 2002).

LI characterizes the places of high landscape significance and the archaeological sites; these places have a LI equal to "1", all the others have a LI equal to "0".

The final value of ILand is calculated with the following formula:

$$ILand_{[0-1]} = LS_{[0-1]} + LI_{[0;1]} \quad \text{with} \quad ILand_{[0-1]} = \begin{cases} LS if LI = 0 \\ LI if LI = 1 \end{cases} \tag{6}$$

Areas with LI = 1 are considered so important from the landscape point of view to determine the value (= 1) of the whole ILand.

Agricultural use index

The agricultural use (IAgr) index is calculated by associating to each LULC class a score that express its value from the agricultural production point of view. The values are based on Metland (Fabos, 1978), used by the Lombardy Regional Authority for the assessment of the agricultural productivity value (Regione Lombardia, 2008). IAgr ranges from "0" (urban LULC classes) to "1" (productive agricultural LULC classes) (Table 2).

Composite land quality index

The composite LQI is the weighted sum of the four indexes IPed, INat, ILand and IAgr, obtained using the following formula:

$$LQI_{[0-1]} = (P1_{[0-1]} x IPed_{[0-1]}) + (P2_{[0-1]} x INat_{[0-1]}) + (P3_{[0-1]} x ILand_{[0-1]}) + (P4_{[0-1]} x IAgr_{[0-1]}) \tag{7}$$

where:

P1, *P2*, *P3* and *P4* are different weights assigned to indexes, based on the importance assumed by each characteristic in the specific territorial context.

In order to take adequately into account the soil weakness (W), NS and LI, LQI = 1 if W = 1, or if NS = 1, or if LI = 1.

Of course, changing the weight of each index can lead to a better interpretation of each specific territorial situation. The weight assignment should be the expression of the case-specific relative importance of the different territorial characteristics and can be done involving local stakeholders and/or experts and using specific statistical procedures (Ferrario *et al.*, 2014).

For this study, we involved six national experts (three form inside the Brescia province and three outside) in order to define four possible scenarios and the relative weights.

The four scenarios defined were the following.

- *Scenario 1*: the pedological, natural, landscape and productive qualities of the territory have equal importance.
- *Scenario 2*: the pedological qualities are more important than the natural and landscape ones, while the productive aspect is the least important.
- *Scenario 3*: the natural and landscape qualities are more important than the pedological ones, while the productive aspect is the least important.
- *Scenario 4*: the productive aspect is more important than the natural and landscape qualities, while the pedological aspect is the least important.

Through the analytic hierarchy process (AHP), we assessed the relative importance (weights) of each component (expressed by the four single indexes IPed, INat, ILand and IAgr).

The AHP was introduced for the first time by Saaty (1980) and has become one of the most widely used multi-criteria decision making tools. AHP is a quantitative method for selecting alternatives based on their relative importance with respect to different criteria. Alternatives are structured into a hierarchical tree-like framework, where they are compared pairwise, according to a nine-step individual judgment scale (Koschke *et al.*, 2012). Moreover, AHP can be easily incorporated into GIS procedures (Modica *et al.*, 2016), in order to derive the weights to be associated to the different attributes of the map layers (Ferrario *et al.*, 2014). For each priority matrix, we also checked the reliability of the preferences by calculating the consistency ratio (C.R.), as follows:

$$C.R.=(C.I.)/(R.I.) \tag{8}$$

where

$$C.I.=(\lambda\_max - n)/(n-1) \tag{9}$$

represents the consistency index (measuring the consistency of the judgments across all pairwise comparisons) with λ_max corresponding to the main eigenvalue of the matrix and n to the number of matrix components;

R.I. corresponds to the random index, an arithmetic mean of random matrix consistency indexes.

In the present study, the C.R. always remained below 3%, thereby proving the congruity of the preferences. The final weights obtained for each index are shown in Table 3. The overall sum of all the weights, for each scenario, is always equal to 1.

Results and discussion

Pedological index

Figure 3A shows the IPed map of the study area. Areas with greater pedological quality (Class 1, with IPed >0.75) occupy the 16% of the territory. About the half of these are characterized by the presence of limitations, with soil weakness (W) equal to "1".

Table 3. Final weights obtained by analytic hierarchy process for each index and each scenario.

Index	Weights			
	Scenario 1	Scenario 2	Scenario 3	Scenario 4
IPed	0.250	0.535	0.143	0.073
INat	0.250	0.196	0.402	0.196
ILand	0.250	0.196	0.402	0.196
IAgr	0.250	0.073	0.053	0.535
	1.000	1.000	1.000	1.000

IPed, pedological index; INat, naturalistic index; ILand, landscape index; IAgr, agricultural use index.

The others Class 1 areas are concentrated in the north-east and central part of the municipality, very closed to the urbanized area and subject to human pressure.

The class 2 areas (IPed = 0.51 - 0.75) occupy almost the 18%, while the class 3 (IPed = 0.26 - 0.50) and 4 (IPed = 0.01 - 0.25) occupy just over 24% and 17% of the territory respectively (with a 24.6% of urbanized area).

We calculated the overall average IPed ($IPed_{TOT}$) for the study area, as follows:

$$IPed_{TOT} = \frac{\sum IPed_i \times Area_i}{Area_{TOT}} \tag{10}$$

where:
$IPed_i$ represents the IPed value for the *i-th* polygon in the municipality;
$Area_i$ represents the area of the *i-th* polygon in the municipality;
$Area_{TOT}$ represents the total area of the municipality.

The study area presents a value of $IPed_{TOT}$ equal to 0.42. The value is not high, also because of the presence of a 24.6% of urbanized area (excluding the urbanized area, the $IPed_{TOT}$ value is 0.56). The 56% of the study area presents a IPed value greater than 0.42.

If we calculate the IPed value independently from the presence of limitations (not putting IPed = 1 if the soil weakness W = 1), the $IPed_{TOT}$ value decreases to 0.37. In this general situation of medium-low pedological quality, safeguarding territories with high pedological quality from urbanization becomes even more strategic.

Naturalistic index

Figure 3B shows the INat map of the study area. Areas with greater naturalistic quality (Class 1, with INat >0.75) occupy less than 1% of the territory (about 9.6 ha, 1/3 of which with a particular naturalistic sensitivity, *i.e.* NS = 1).

The class 2 (INat = 0.51 - 0.75) and class 3 (INat = 0.26 - 0.50) areas occupy almost the 6% and just over 11% of the territory respectively. They are concentrated in two areas in the north part of the municipality; the most part of them surround the north-west urbanized area and are subject to high human pressure.

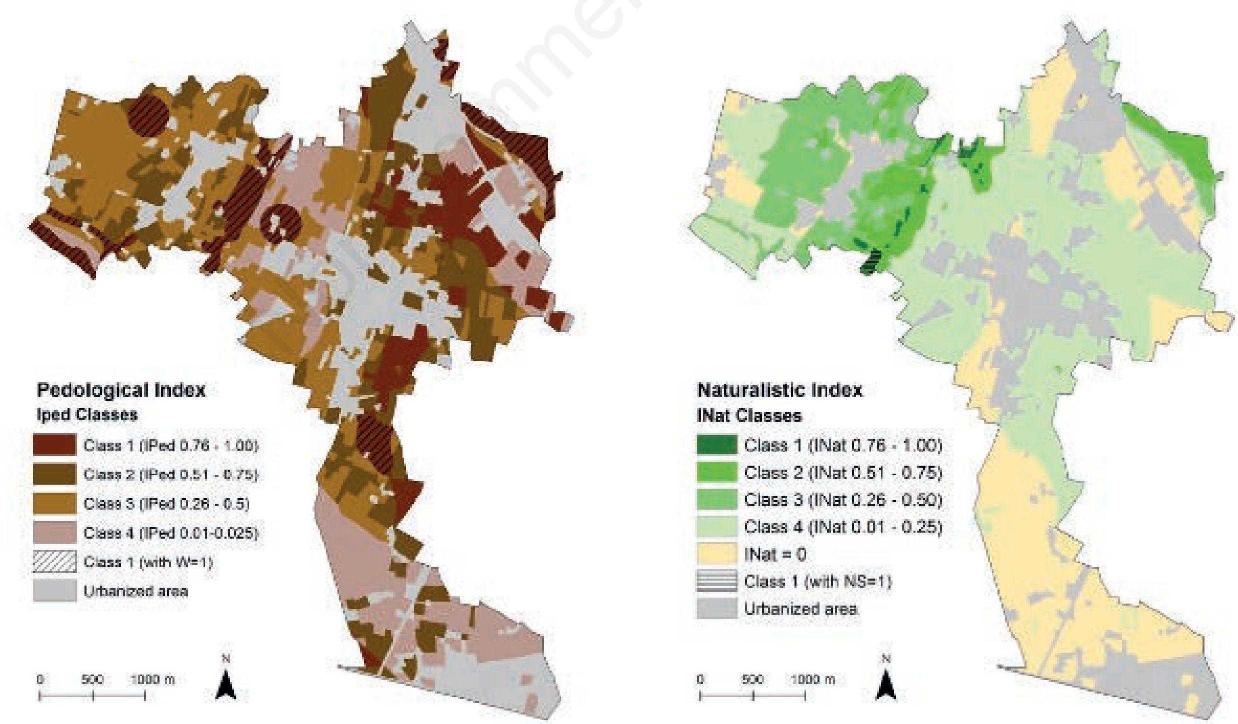
The class 4 areas (INat = 0.01 - 0.25) occupy almost the 34% of the territory and are concentrated in the central part of the municipality. The 25% of the territory (concentrated in the southern part of the study area) is characterized by the absence of a naturalistic value (INat = 0).

Also, for the naturalistic quality we calculated the overall average INat ($INat_{TOT}$) for the study area, as follows:

$$INat_{TOT} = \frac{\sum INat_i \times Area_i}{Area_{TOT}} \tag{11}$$

where:
$INat_i$ represents the INat value for the *i-th* polygon in the municipality;
$Area_i$ represents the area of the *i-th* polygon in the municipality;
$Area_{TOT}$ represents the total area of the municipality.

The study area presents a value of $INat_{TOT}$ equal to 0.14, with only the 25% of the study area with a INat value greater than 0.14.



A

B

Figure 3. A) Pedological index map for the study area; B) Naturalistic index map for the study area.

The value of $INat_{TOT}$ is quite low, indicating the general low naturalistic quality of the area and, therefore, the strategic necessity to safeguard these few areas from urbanization.

Landscape index

Figure 4A shows the ILand map of the study area. Almost all the non-urbanized territory has some landscape quality (less than 1% has ILand = 0).

Areas with greater landscape quality (Class 1, with ILand >0.75) occupy almost 6% of the territory (about the 60% of these are areas of high landscape significance or archaeological sites, with LI equal to "1"). Some of class 1 areas are very close to the urbanized areas.

Class 2 areas (ILand = 0.51 - 0.75) occupy almost the 35% of the territory and are concentrated in the north part of the study area.

Class 3 areas (ILand = 0.26 - 0.50) occupy almost the 27% of the territory and are concentrated in the south and west part of the study area.

Class 4 areas (ILand = 0.01 - 0.25) occupy almost the 7% of the territory and are concentrated in the southernmost part of the municipality.

Also, for the landscape quality we calculated the overall average ILand ($ILand_{TOT}$) for the study area, as follows:

$$ILand_{TOT} = \frac{\sum ILand_i \times Area_i}{Area_{TOT}} \quad (12)$$

where:
$ILand_i$ represents the ILand value for the *i-th* polygon in the municipality;
$Area_i$ represents the area of the *i-th* polygon in the municipality;
$Area_{TOT}$ represents the total area of the municipality.

The study area presents a value of $ILand_{TOT}$ equal to 0.47. The value is not high, also because of the presence of a 24.6% of urbanized area (excluding the urbanized area, the $IPed_{TOT}$ value is 0.63. Almost 70% of the study area presents a ILand value greater than 0.47.

The landscape quality of the study area is generally medium-high, particularly in the northern part, trapped between several urbanized zones. Here, the safeguarding of areas with high landscape quality from urbanization becomes strategic.

Agricultural use index

Figure 4B shows the IAgr map of the study area. Almost all the non-urbanized territory has some quality value from the agricultural production point of view (only 1.2% has IAgr = 0).

Almost 70% of the territory is in class 1 (IAgr >0.75), demonstrating the agricultural vocation of the area. 42% of the class 1 areas is occupied by vineyards: the whole territory of Passirano is part of the Franciacorta area, famous for its high-quality sparkling wines, and is included in designation of origin areas *DOC* (*denominazione di origine controllata*, denomination of controlled origin) and *DOCG* (*denominazione di origine controllata e garantita*, denomination of controlled and guaranteed origin), the Italian system of labeling and legally protecting Italian wine.

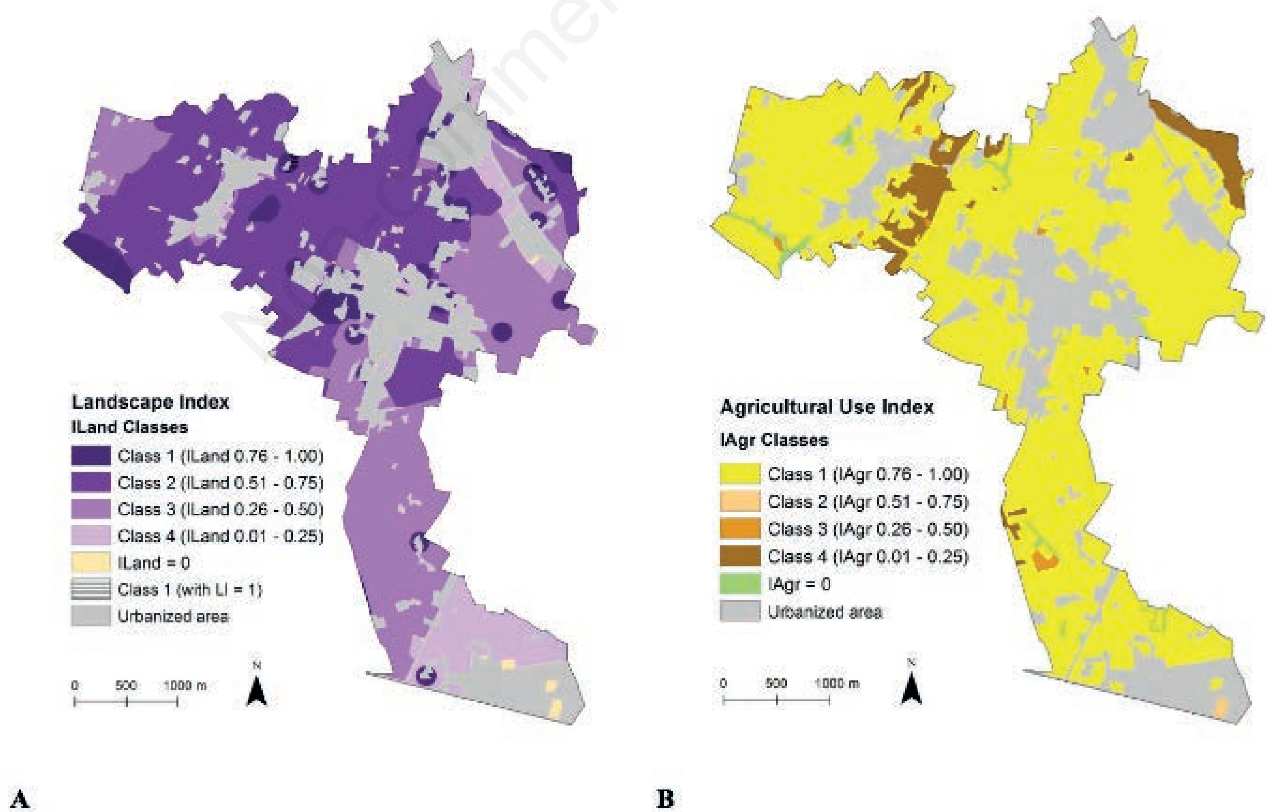


Figure 4. A) Landscape index map for the study area; B) Agricultural use index map for the study area.

Class 2 (IAgr = 0.51 - 0.75) and class 3 (IAgr = 0.26 - 0.50) areas occupy 0.3% and 0.5% of the territory respectively.

Class 4 areas (IAgr = 0.01 - 0.25) occupy the 5% of the territory and correspond to the areas with greater naturalistic quality (Class 1 and 2 of INat).

Also for the quality value from the agricultural production point of view we calculated the overall average IAgr ($IAgr_{TOT}$) for the study area, as follows:

$$IAgr_{TOT} = \frac{\sum IAgr_i \times Area_i}{Area_{TOT}} \qquad (13)$$

where:

$IAgr_i$ represents the IAgr value for the *i-th* polygon in the municipality;

$Area_i$ represents the area of the *i-th* polygon in the municipality;

$Area_{TOT}$ represents the total area of the municipality.

The study area presents a value of $IAgr_{TOT}$ equal to 0.62. The value is quite high and, excluding the urbanized area, it reaches 0.82. 68% of the study area presents a IAgr value greater than 0.62.

Composite land quality index

Figure 5 shows the LQI map of the study area, for each of the four scenarios defined, while Figure 6 shows the relative importance of the LQI Classes in each scenario.

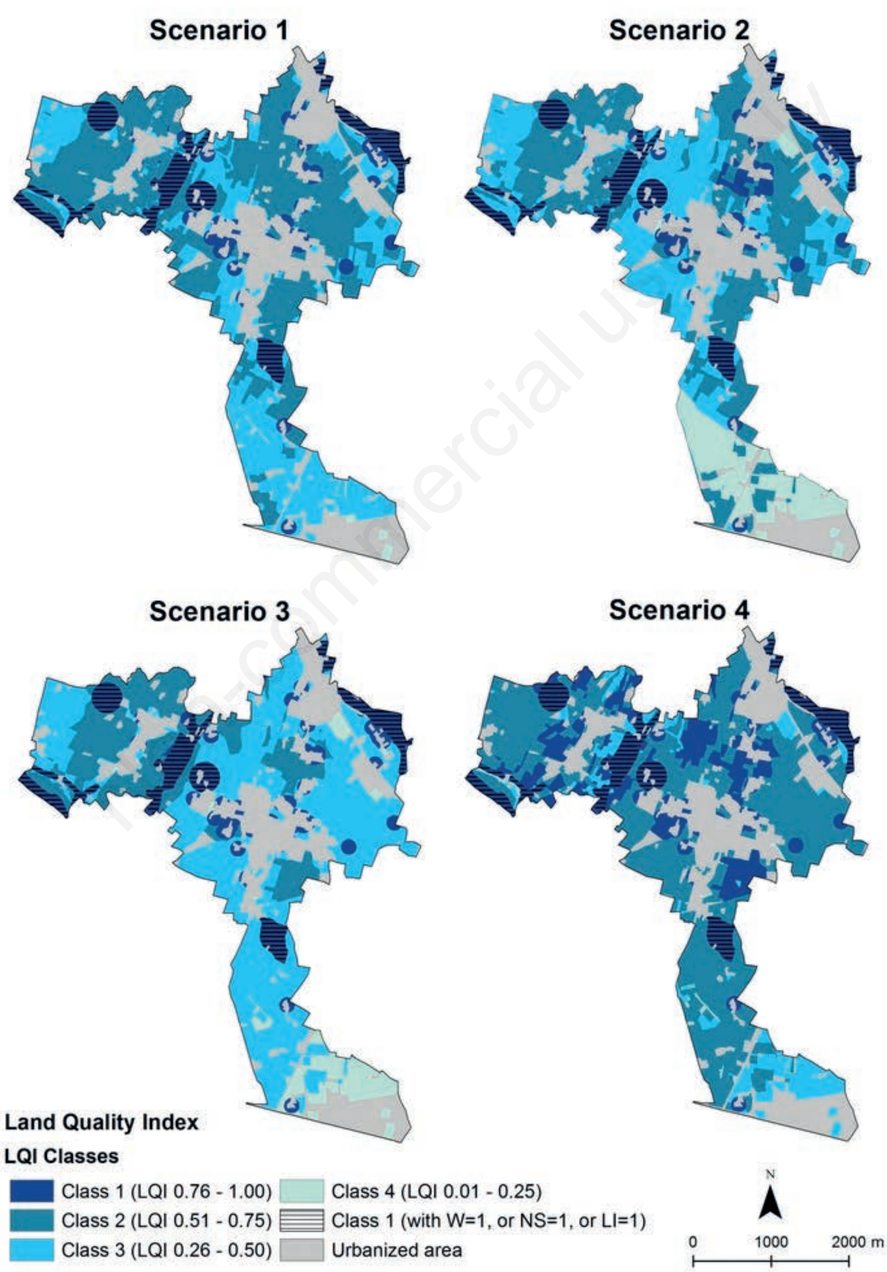


Figure 5. Land quality index (LQI) in the four scenarios.

Areas with greater overall quality (Class 1, with LQI >0.75) occupy 12-13% of the territory in the first three scenarios, while in scenario 4 it reaches 21% (due to the general high quality of the study area from the agricultural production point of view). Also, the geographical location of the class 1 areas are very similar in the first three scenarios (Figure 5). This is because the 99% of the class 1 areas in scenarios 1 and 3, and the 92% in scenario 2, are the same areas, *i.e*. areas with soil weakness (W) or NS or LI equal to 1.

Only in scenario 4, these areas of particular fragility occupy just over 50% of the class 1 areas.

Class 2 (LQI = 0.51 - 0.75) occupies 39% and 31% of the territory in scenario 1 and 2 respectively, about the half (17%) in scenario 3 (due to the low naturalistic quality of the study area) and, as expected, 46% in scenario 4.

Class 3 (LQI = 0.26 - 0.50) occupy 23-24% of the territory in the first two scenarios, 41% in scenario 3 (always because of the low naturalistic quality of the study area) and, as expected, only 7% in scenario 4.

Class 4 areas (ILand = 0.01 - 0.25) occupy 9% and 5% of the territory in scenario 2 and 3 respectively and are concentrated in the southernmost part of the municipality, the area with the lowest overall quality.

Also, in this case we calculated the overall average LQI (LQI_{TOT}) for the study area, as follows:

$$LQI_{TOT} = \frac{\sum LQI_i \times Area_i}{Area_{TOT}} \quad (14)$$

where:
LQI_i represents the LQI value for the *i-th* polygon in the municipality;
$Area_i$ represents the area of the *i-th* polygon in the municipality;
$Area_{TOT}$ represents the total area of the municipality.

We calculated LQI_{TOT} for each scenario: 0.45 for scenario 1, slightly lower for scenarios 2 and 3 (0.42 and 0.39 respectively), and, as expected, fairly larger for scenario 4 (0.52).

The calculation of an overall average index value (LQI_{TOT}) allows: i) on the one hand, to evaluate *ex-ante* different hypotheses of land use modifications, calculating the decrease in the value of the index once the assumed transformation has been carried out, in order to choose the option that safeguards as much as possible the quality of the territory, minimizing the loss of ecosystem services; ii) on the other hand, to establish objectives and thresholds within the planning process (*e.g*. maximum reduction in landscape quality of 20% over the next 20 years) and to monitor the achievement of these objectives over time.

These assessments can obviously be made for each component separately or by evaluating the overall quality of the territory through the trend of LQI (appropriately weighted).

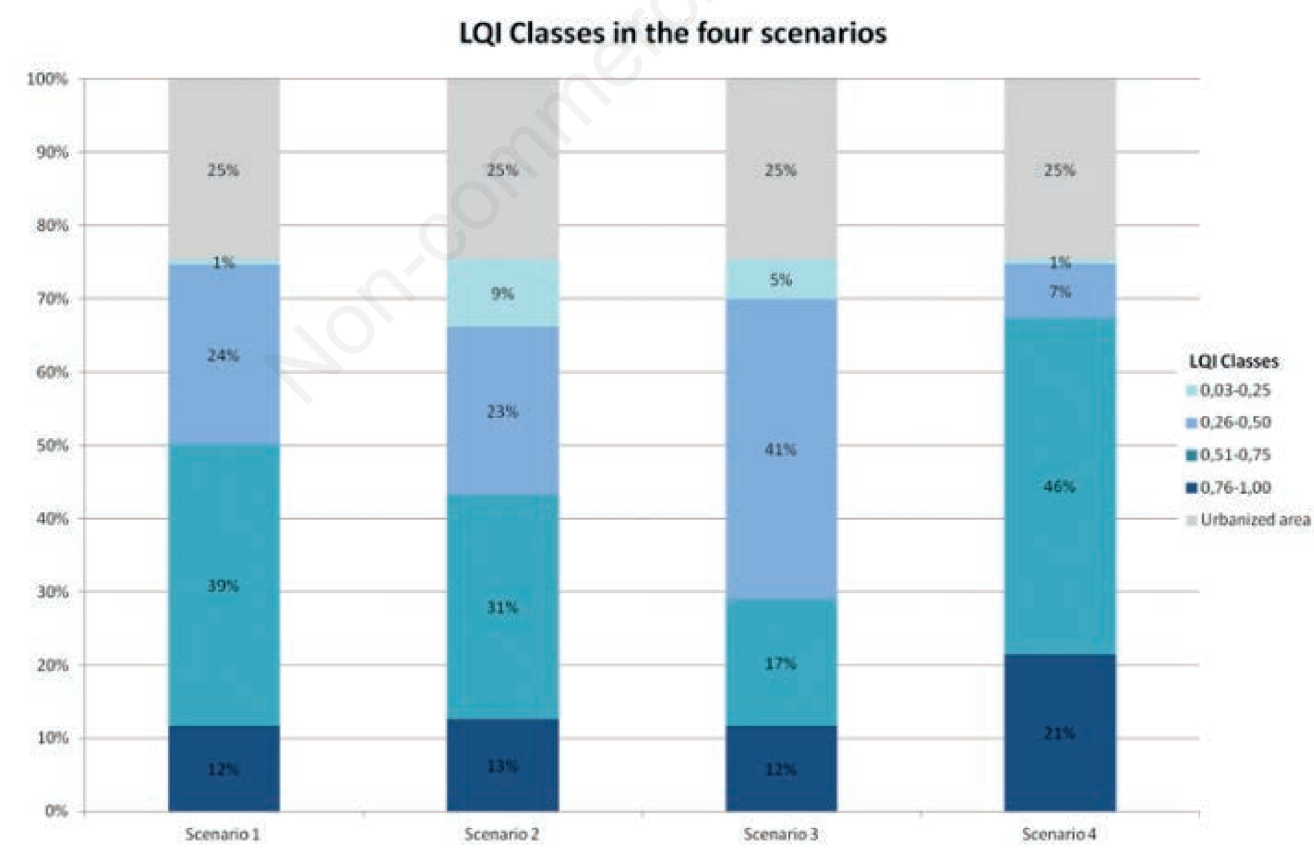


Figure 6. Relative importance of land quality index (LQI) classes in the four scenarios.

Conclusions

Land take is a global phenomenon that continues to grow and causes degradation of the environmental conditions and loss of important ecosystem services. It is not only a problem of reducing the quantity of land loss, but it is always more clear that the quality of the land taken has to be assessed and adequately considered during the land-use planning process.

The quality of non-urbanized territories is not easy to define, but their ability to provide a plurality of ecosystem services can be used as a measure of their quality.

The aim of the work was to develop a methodology useful to assess the *quality* of the territory that could be *lost* in the process of land take, in order to know in advance and guide the land-use planning process in a direction that prevents the loss of the most valuable parts of our agricultural/natural territory.

More specifically, the paper shows how it has been defined and calculated a composite LQI: the methodology has been applied to a Lombard case study in order to verify its capability to be used to realize the *land quality map* at municipal level, as actually required by the law.

The developed methodology allows to assess the quality of a given territory in a rigorous and transparent way, according to a clear procedure based on official data. LQI represents an objective index useful to identify the areas to preserve from future land take.

LQI can support the land-use planning process comparing different hypotheses in an ex-ante evaluation of land use transformations and helping to choose the option that safeguards as much as possible the quality of the territory, minimizing the loss of ecosystem services.

Moreover, LQI can be used to define and calculate quantitative thresholds based on the quality of the territory and to monitor its trend over the time.

More generally, the calculation of an index that evaluates the *composite quality* of the territory, can be used for measuring the ecosystem services offered by the green territory (Senes and Cirone, 2018) within sustainable land-use planning and environmental assessment processes (De Montis *et al.*, 2014).

The application to the study area shows how the method can be applied effectively, using geographical official data currently available, without the need for specific surveys. This is a particularly important aspect, given the chronic absence of human and economic resources in which the local authorities stay.

The validity of the approach and the results is demonstrated by the fact that the town Council of Passirano adopted the study as a basis for the development of its land-use plan.

Future applications to other territories, in different geographical contexts, can be useful to compare the results and carry out any necessary adaptations to specific situations.

References

Colsaet A., Laurans Y., Levrel H. 2018. What drives land take and urban land expansion? A systematic review. Land Use Policy. 79:339-49.

CRCS. 2018. Consumo di suolo, servizi ecosistemici e green infrastructures: caratteri territoriali, approcci disciplinari e progetti innovativi. Rapporto 2018. INU Edizioni, Roma, Italy.

De Montis A., Ledda A., Caschili S., Ganciu A., Barra M. 2014. SEA effectiveness for landscape and master planning: An investigation in Sardinia. Environ. Impact Assess. 47:1-13.

Decoville A., Schneider M. 2015. Can the 2050 zero land take objective of the EU be reliably monitored? A comparative study. J. Land. Use Sci. 1-19.

Diti I., Tassinari P., Torreggiani D., 2015. The agri-environmental footprint: A method for the identification and classification of peri-urban areas. J. Environ. Manage. 162:250-62.

European Commission. 2016. Science for Environment Policy. Future brief: No net land take by 2050? Issue 14. Doi: 10.2779/537195.

European Environmental Agency. 2010. Land take Indicator Specification. Indicator codes: CSI 014, LSI 001 (created 27 Sep 2010, published 05 Jan 2011, last modified 09 Sep 2019. Available from: www.eea.europa.eu/data-and-maps/indicators/land-take-2

European Environmental Agency. 2019. Land take 2000-2018 Dashboard. Prod-ID: DAS-106-en. Published 10 Sep 2019. Available from: www.eea.europa.eu/data-and-maps/dashboards/land-take-statistics

Fabos J.G. 1978. The Metland Landscape Planning Process: Composite Landscape Assessment, Alternative Plan Formulation and Plan Evaluation, Research Bulletin n. 653, University of Massachusetts, Amherst, USA.

Ferrario P., Fumagalli N., Senes G., Toccolini A. 2014. Composite assessment of productive, protective and recreational functions in forest planning. Environ. Eng. Manag. J. 13:1277-90.

Grădinaru S.R., Kienast F., Psomas A. 2019. Using multi-seasonal Landsat imagery for rapid identification of abandoned land in areas affected by urban sprawl. Ecol. Indicat. 96:79-86.

Haines-Young R., Potschin-Young M. 2018. Revision of the Common International Classification for Ecosystem Services (CICES V5.1): A Policy Brief. One Ecosyst. 3:e27108.

ISPRA. 2018. Consumo di suolo, dinamiche territoriali e servizi ecosistemici. ISPRA, Roma, Italy.

Koschke L., Fürst C., Frank S., Makeschin F. 2012. A multi-criteria approach for an integrated land-cover-based assessment of ecosystem services provision to support landscape planning. Ecol. Indicat. 21:54-66.

Modica G., Pollino M., Lanucara S., La Porta L., Pellicone G., Di Fazio S., Fichera C.R., 2016. Land Suitability Evaluation for Agro-Forestry: Definition of a Web-Based Multi-Criteria Spatial Decision Support System (MC-SDSS): Preliminary Results. In: Gervasi O., et al. (Eds.), Computational Science and Its Applications - ICCSA 2016. ICCSA 2016. Lecture Notes in Computer Science, vol 9788. Springer, Cham. https://doi.org/10.1007/978-3-319-42111-7_31.

OECD, 2017. Land-use Planning Systems in the OECD. Country Fact Sheets. Published on May 02, 2017. Available from: www.oecd.org/publications/land-use-planning-systems-in-the-oecd-9789264268579-en.htm

Regione Lombardia. 2002. D.G.R. 8 novembre 2002 n. 7/11045, Approvazione "Linee guida per l'esame paesistico dei progetti" prevista dall'art. 30 delle Norme di Attuazione del Piano Territoriale Paesistico Regionale, BURL 21 novembre 2002.

Regione Lombardia. 2008. D.G.R. 19 settembre 2008 n. 8/8059, Criteri per la definizione degli ambiti destinati all'attività agricola di interesse strategico nei Piani Territoriali di Coordinamento Provinciale, BURL 29 settembre 2008.

Regione Lombardia. 2014. Legge Regionale 28 novembre 2014 n. 31, Disposizioni per la riduzione del consumo di suolo e per la riqualificazione del suolo degradato, BURL 1 dicembre 2014.

Regione Lombardia. 2017. Uso e copertura del suolo 2015 (DUSAF 5.0). Available from: www.geoportale.regione.lombardia.it

Ronchi S., Salata S., Arcidiacono A., Piroli E., Montanarella L., 2019. Policy instruments for soil protection among the EU member states: A comparative analysis. Land Use Policy. 82:763-80.

Saaty T.L. 1980. The analytic hierarchy process. McGraw-Hill, New York, US.

Senes G., Cirone G. 2018. I servizi ecosistemici del territorio rurale. La valutazione della qualità dei territori non urbanizzati come misura dei servizi ecosistemici a scala comunale. In: CRCS, 2018. Consumo di suolo, servizi ecosistemici e green infrastructures: caratteri territoriali, approcci disciplinari e progetti innovativi. Rapporto 2018. INU Edizioni, Roma, Italy.

Tassinari P., Torreggiani D., Benni S. 2013. Dealing with agriculture, environment and landscape in spatial planning: A discussion about the Italian case study. Land Use Policy 30:739-47.

Vizzari M., Sigura M. 2015. Landscape sequences along the urban–rural–natural gradient: A novel geospatial approach for identification and analysis. Landscape Urban Plan. 140: 42-55.