From quantitative to qualitative analysis of Land-Take. The application of a Composite Indicator for targeted policies of Land Take reduction

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Abstract

The processes of land take and soil sealing tend to receive more attention as threats to soil resources and Ecosystem Services (ES) provided by soil grow. The objectives of this paper are: 1) to assess the extent of land take (intended as the of artificial surfaces) in the Province of Lodi (Northern Italy) by evaluating the accuracy associated to the different scales of the cartography used; 2) to assess the effects of land take on the selected ES (in particular, supporting and regulating services). In case of study the ES assessed was the potential agricultural productivity, evaluated the Land Capability Classification[1] as proxy and integrated with additional information regarding the increase of impervious surfaces. Thus, the construction of an experimental Composite Indicator on Land Take has been provided.

The results have shown that important underestimation of land take occurs when Corine Land Cover[2] (CLC) is used at local level in Italy but, at the same time, when used in Country, CLC seems to be sufficient to assess the general amount of Land Take. Moreover, when a shift from the neutral assessment to practical policy orientation of Land Take reduction is requested, a higher degree of additional qualitative information necessary to steer planning options. The Composite Indicator is aimed to help policy makers and planners to adopt suitable measures by applying European guidelines and protocols for Land Take government.

1. Introduction

The term "land take" refers to a complex transformation process which involves land surface and is detected and mapped by Land Use Change (LUC) analysis (Hasse e Lathrop 2003; Antrop 2004). It is generally defined as the conversion of natural, seminatural or agricultural land uses into artificial land uses (European Commission, Guidelines on best practicies to limit, mitigate or compensate soil sealing 2012), as a consequence of urban growth. This process generally implies a reduction of the ecosystem services delivered by these areas, and in particular, capability to support agricultural productivity.

The large majority of soil indicators for Land Take assessment are consistent only as descriptive tools for soil scientists, but less consistent as tools to steer local policies for preserving soil degradation due to urbanization (Geneletti, Assessing the impact of laternative land-use zoning policies on future ecosystem services 2013).

Nowadays the data collected on the urbanization trend (land-cover classification, rate of change, urbanization per capita) is being well analyzed (Benini, *et al.* 2010; Bhatta, Saraswati e Bandyopadhyay 2010; Munafò 2013) (Pileri e Salata, L'intensità del consumo di suolo. Lombardia, Emilia Romagna, Friuli Venezia Giulia e Sardegna 2011) and the proposed European guidelines for land-take reduction are supported by national databases of land cover/use. Less analyses are focused on environmental effect of land take on ecosystem services (ES) (Daily, 1997; Costanza, *et al*., 1997), that are provided by natural soils (Helian, Shilong, Hang, & Xiaodong, 2011), especially the ones that require integrative analysis at local level across different disciplines (Breure, *et al*., 2012). Despite this, a great deal of recent research is dedicated to the use ES as a proxy for planning policy for sustainable management of soil (Artmann, 2014; Breure, *et al*., 2012; Jansson, 2013; Li, *et al*., 2014).

There is still a gap between national policies and the construction of a theory of land resource management, includ-

1. Land Capability Classification (LCC) shows the suitability of soils for most kinds of agricultural activity. Capability classes are designed to indicate progressively limitations for agricultural uses.

2. In 1985 the Corine programme was initiated in the European Union. Corine means 'coordination of information on the environment' and it was a prototype project touching upon many different environmental issues. The Corine databases and several of its programmes have been taken over by the EEA. One of them is an inventory of land cover in 44 classes, and presented as a cartographic product, at a scale of 1:100 000. This database is operationally available for most areas of Europe. (definition given by European Environment Agency – Terminology and Discovery Service.

ing regulative (intended as quantitative target – e.g., 30 ha per day), planning (intended as local prescription – e.g., Urban Growth Boundaries) and fiscal measures (intended as special fees – e.g., additional taxes for land transformation) for limiting land take (Dale e Kline 2013). The goal of reducing land take with an integrative approach between analysis and policies of local land regulation needs to be supported by a deeper consideration of two crucial aspects: land-use detection and the development of synthetic indicators for a multidimensional approach to land-take evaluation.

Soil protection strategies based on policies, practices and planning tools directed towards land take reduction were progressively introduced by the Strategic Environmental Assessment (SEA Directive, 200142/EC). SEA is aimed at monitoring the land take phenomena, using environmental data, and assessing impacts of land use change due to urbanization (Treville 2011). The concept of environmental sustainability was enforced by SEA Directive, but repeatedly even fully exploited, SEA is not sufficiently qualified to perform a complete land take assessment. Mainly SEA uses a basic quantitative analysis rather than qualitative and coherent assessment of soil degradation to quantify the cumulative impact induced by land take (Tardieu, Roussel e Salles 2013). This happens even if predicting effects on ES has emerged as a crucial need in spatial planning and in the associated SEA (Geneletti, Reasons and options for integrating ecosystem services in strategic environmental assessment of spatial planning 2011).

Traditionally, LUC analysis only allows quantifying a single process, and not the effects that the changes in land use have on ES. For example, the traditional analysis of land take does not provide any information on potential food production (Gardi, Bosco e Rusco 2009; Gardi, Panagos e Van Liedekerke 2014). When a process of urbanization occurs, at least three critical processes are simultaneously happening: the first one is the simple variation of land covers which implies, among others, radical changes on carbon sequestration services (Lal 2004); the second one is the "sealing process" (Duley 1939; Scalenghe e Ajmone Marsan 2009) which implies the coverage of surfaces with impervious material and it generally implies major effects on soil buffering capacity; finally, the third process is represented by the alteration of potential productivity of soil (Helian, *et al*. 2011; Haines-Young e Potschin 2011) which directly affects the local and global food production and the related risks.

Above all, ordinary LUC analysis that is highly affected by land-use detection: the topography, variability among data, classification systems, projections systems and technologies adopted can cause a significant effect on the plain measure of land use areas.

As previously mentioned, planners have to analyze the problems through interdisciplinary research that shifts from traditional boundaries between the social sciences, humanities and natural sciences (Haberl & Wackernagel, 2004), going through the traditional study on surface covers and identifying new land use models (Geneletti, 2013). Therefore it is crucial to simplify the production of land-take indicators and (EAA 2011; Pileri, Misurare il cambiamento. Dalla percezione alla misura delle variazioni d'uso del suolo 2011) is crucial to simplify and qualify information on complex ongoing processes of land transformation. Reliable indicators are usually very specialized and soil-oriented, but not easily applicable in practical land-use planning or policies. The proposal of the present (research) paper, tested only from methodological standpoint, is that a composite indicator on land-take impact could help planners on the prescriptive level of soil uses. The paper will present the research output for a context-based assessment (Province of Lodi, Italy) of a composite indicator on land take (Land Take Impact - LTI) (Giovannini, *et al*. 2008). According to the OECD definition "A composite indicator is formed when individual indicators are compiled into a single index, on the basis of an underlying model of the multidimensional concept that is being measured" (OECD 2004).

Traditional LUC analysis (useful for "quantitative - target" policies for land-take limitation) will be integrated (and discussed) with additional qualitative information. The research shows limitations of considering LUC an efficient tool for supporting urban planning at local scale. In fact, the composite indicator on Land Take Impact (LTI) seems to demonstrate the natural limits and weaknesses of the traditional analysis as a technical tool to qualify land-take processes and suggests how ecosystem services support land-use management.

2. Land-use change analysis. From the traditional approach to innovative ones

Approximately 75% of Europe's population lives in urban environments and a quarter of EU's land surface has been directly affected by urbanization (EEA, 2006). This type of land-use change affects urban climate through alteration in surface-atmosphere interactions through energy fluxes (Nordbo, Jarvi, & Vesala, 2012). Land-use change has become a "hot topic", and this is normal in a global context of population growth (Cohen 1995; Rounsevell e Reay 2009).

The general impression is that the gap between analysis (quantification and qualification of land take phenomena) and regulation (improvement of particular land-use development patterns) is still unfilled (Nuissl, *et al*. 2009). Such problem occurs due to a deep epistemological issue: while "land cover" refers to the ecological state and physical appearance of the land surface based on a classification system, "land use" refers to human purposes in relation to the land (Dale e Kline 2013; Turner II e Meyer 1994).

According to Nuissl *et al*. (2009), the tools focusing on the containment of land take are aimed to define two different aspects: reducing the amount of land development and improving land use patterns. While the first field theory is much more advanced and rooted in environmental sciences (Helming, *et al*. 2011), the second field is still uncovered by scientific studies (Haberl e Wackernagel 2004).

National agenda of environmental policies would need to be supported by aggregated data concerning the levels of urbanization: all the Nations engaged in the discussion of an instrument that will limit the further growth of urban areas (Germany, Netherlands, UK, etc.) are supported by national databases of land cover/use. However, a theoretical model for land use management at local scale specifically created for limiting land take is still lacking where advanced policies are designed (Dale e Kline 2013).

Local planning policies are unique and cannot be used as templates (Lenz e Peters 2006) as, in accordance with the subsidiarity principle, the lowest level possible should be responsible for land-use management, and planning instruments should directly control urban growth, but all too often they have failed to do so at local level despite the central guidelines, protocols and policies (EEA 2006).

2.1 Land-take detection

As introduced above, the comparability between different land-use databases is necessary for LUC analysis, in fact, it requires comparable land-use maps produced through the harmonized process, with the same scale of representation, the same number of land-use classes and the same minimum detectable areas (Benini, *et al*. 2010).

LUC analysis is one of the major tasks of landscape research, so far, has been implemented with the use of different temporal threshold databases of land use and the impact assessment of land-use transition, referred to land take and land abandonment, is one of the major tasks of landscape research (Wu e Hobbs 2002; Salata 2014).

Accurately detecting land use is a difficult challenge for the further development of relevant indicators of land take and for the purpose of its limitation. For instance, it is widely accepted that the reliability of aggregated land-use data at different scales is affected by different gradients of precision. An underestimation of artificial surface in the database of Corine Land Cover (CLC) is supposed to be evident because of its main technical parameters (Prokop, Jobstmann e Schonbauer 2011), but a misinterpretation of landscape indicators arises when users are not aware of the differences between data sources (Lenz e Peters 2006).

A comparison among land-use maps at different scales demonstrates that large scale land use databases can sometimes be sufficiently precise for spatial analysis. To test this hypothesis, a cartographic and statistic comparison among different land use databases is being presented here for two territorial contexts: the Province of Lodi, in the North-West of Italy, and the Region of Catalunya, in Spain.

The European database CLC will be tested at different scales: as in ~~the~~ Italian context, by comparing CLC[3] with the regional land-use database of Lombardy DUSAF[4] andg with a Topographic database of the Province of Lodi[5] (DB top), which is the cartographic instrument for the territorial government at local scale). In the Spanish context, CLC will be tested through a comparison with the Mapa de cobertes del sòl de Catalunya (MCSC-3)[6] which is the regional land-use database.

For the Italian case study the three databases are uniformly clipped and geospatially tested. A comparison among the databases is presented and the aspects under analysis are: variations, indexes and differences of accuracy.

The statistical comparison demonstrates how, in the Italian case, the aggregated data for the land-use classes is strongly influenced by land-take detection among different databases. Two significant points need to be highlighted: the statistical error in artificial surfaces between CLC and DB top (see table 1), and the differences between the detected land-use indexes. The sixty-two percent of the existent built-up system is not detected by CLC (Class 1), while for DUSAF the underestimation is only twelve percent. These results show the inadequacy of CLC for this specific scale of territorial investigation.

3. **Sources**: satellite images SPOT-4 HRVIR, SPOT 5 HRG e/o IRS P6 LISS III **Year**: 2006 **Scale**: 1:100.000 **Minimum unit**: 250.000 mq (25ha) **Legend**: Corine, 3 levels, tot 64 classes.

4. **Sources**: aerial photo by BLOM Crg **Year**: 2007 **Scale**: 1:10.000 **Minimum unit**: 1.600 mq **Legend**: Corine, 5 levels.

5. **Sources**: aerofoto di volo eseguito nel 2008 **Year**: 2008 **Scale**: 1:2.000 **Legend**: 88 classes.

6. **Sources**: *Imágenes de referencia SPOT5 fusión de imágenespancromática y multiespectral de 2,5 m de resoluciónespacial del año 2005 conjuntamente con doscoberturas de imágenes Landsat5 TM del año 2005 y ortofotos PNOA de losaños 2004 y 2006, como complemento***Year**: 2005 **Scale**: 1:25.000 **Minimum unit**: from 2 to 0,5 ha **Legend**: Legenda Siose.

Table 1 – Statistical comparison of cartographic databases for the Italian case.

land use class (absolute values)			
	CLC	DUSAF	Db top
	(ha)	(ha)	(ha)
artificial surfaces	6,818	9,825	11,047
agricultural areas	66,510	62,785	61,024
forest and seminatural	3,654	3,921	3,901
wetland and water	1,335	1,776	2,853
total	78,318	78,309	78,826

variations		
CLC | DUSAF	DUSAF | DB	CLC | DB
(ha)	(ha)	(ha)
-3,007	-1,221	-4,229
3,724	1,761	5,486
-266	19	-247
-441	-1,076	-1,518

land use class (distribution)			
	%	%	%
artificial surfaces	8.7	12.5	14.0
agricultural areas	84.9	80.2	77.4
forest and seminatural	4.7	5.0	4.9
wetland and water	1.7	2.3	3.6
total	100.0	100.0	100.0

proportion		
%	%	%
-30.6	-12.4	-62.0
5.9	2.8	8.2
-6.8	0.5	-6.8
-24.9	-60.6	-113.7

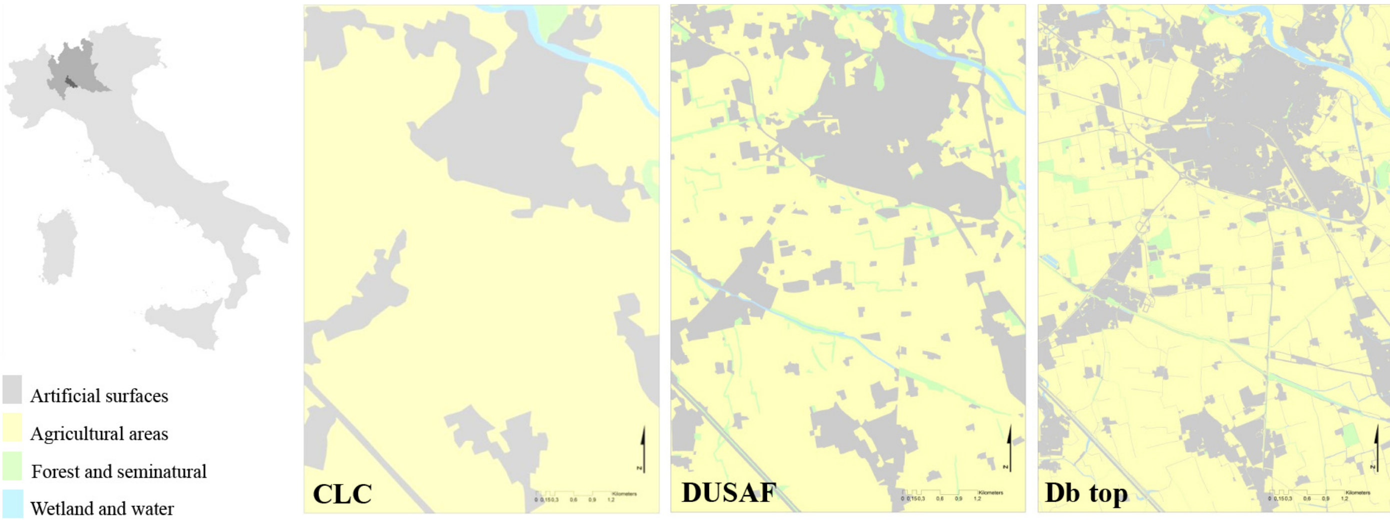

Figure 1 – Cartographical comparison of databases for the Italian case.

Table 2 – Statistical comparison of cartographic databases for the Spanish case.

land use class (absolute values)		
	CLC	MCSC-3
	(ha)	(ha)
artificial surfaces	69,631	71,175
agricultural areas	89,115	61,741
forest and seminatural	163,140	190,895
wetland and water	1,077	552
total	322,965	324,364

variations
CLC | MCSC-3
(ha)
-1,544
27,374
27,754
524

land use class (distribution)		
	%	%
artificial surfaces	21.6	21.9
agricultural areas	27.6	19.0
forest and seminatural	50.5	58.9
wetland and water	0.3	0.2
total	100.0	100.0

proportion
%
-2.2
44.3
-14.5
48.6

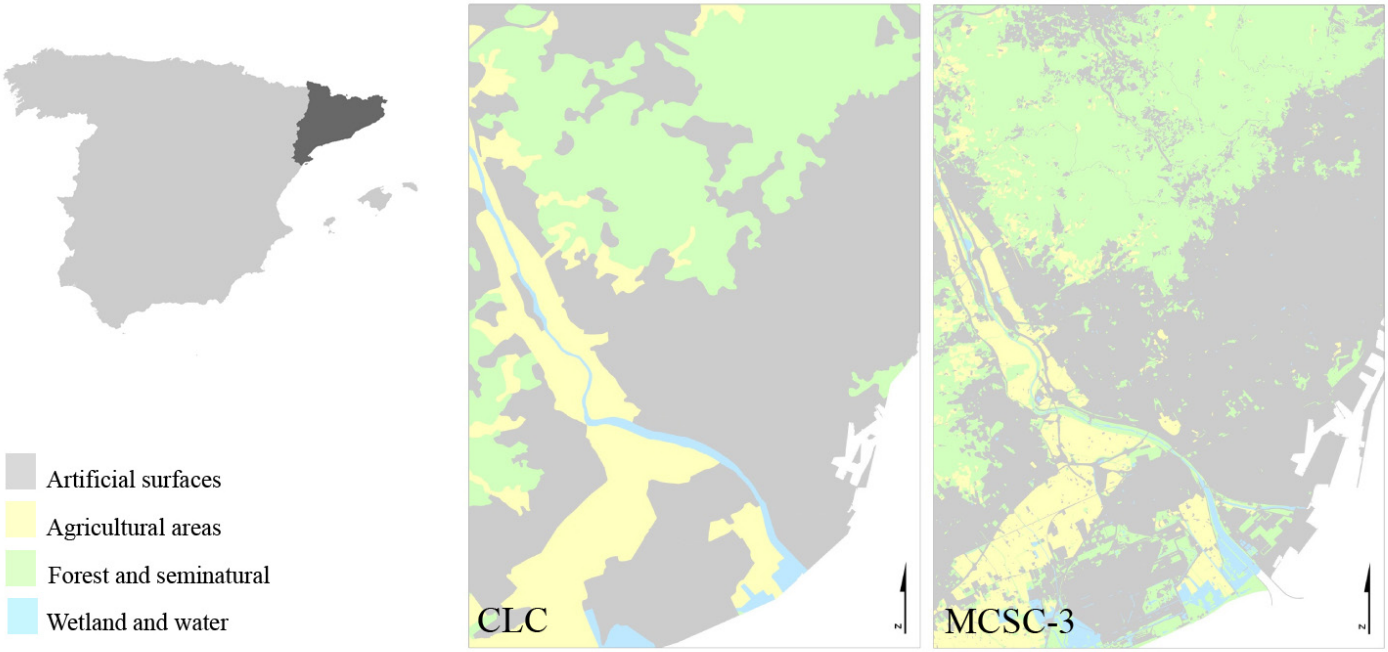

Figure 2 – Cartographical comparison of databases for the Spanish case study.

On the contrary, the analysis of CLC in Catalunya, and its comparison with MCSC-3 shows opposite results: the statistical error of artificial surfaces (table 2) and the difference between the detected land-use index, is much lower (0.3%), and not significant. This means that CLC data on aggregated land use in this specific context can be used for studies at regional scale.

Land take measures are strongly influenced by the land use detection and land-use detection depends on the "context-based" distribution and dispersion of settlements (Antrop 2004). The literature on urban sprawl distinguishes among compact, scattered, strip, poly-nucleated or leapfrogging development (Galster, *et al.* 2001); all these types of developments have direct influence on aggregated data of land use, and consequently on land take measures. The impact of this variability depends on the general characteristics of settlement distribution (Nuissl, *et al.* 2009) and it would be incorrect to standardize the error. As consequence an evaluation of the data sources is necessary before every LUC analysis. The case studies analyzed here show how LUC analysis is generally scale-dependent; this specific aspect is often neglected or insufficiently considered in landscape researches (Dale e Kline 2013; Lenz e Peters 2006).

2.2 A composite indicator of land take impact

The second main problem of LUC analysis is that it only quantifies a single process in the total amount of processes regarding the transformation of topsoil due to urbanization (in particular, it allows to quantify the process of urbanization).

But when a process of urbanization occurs, at least three critical processes, that have been under analysis by various disciplines, are simultaneously happening. One process is the plain variation of land covers indicated by LUC that is normally accounted for statistical changes of land use classes (Geneletti, Assessing the impact of laternative land-use zoning policies on future ecosystem services 2013). A second process is the "sealing process" (Duley 1939) which affects urban covers and has the biggest effect on ecosystems and landscape. Finally a third process, related to the first two, is the alteration in the capacity of soils to provide productive function of the total amount of ecosystem services (ES) (Helian, *et al*. 2011). One of the most crucial services in terms of biomass production is the "productive capacity" of soil, which can be related to the Land Capability Classification.

In fact, when a piece of agricultural land is urbanized, the productive capacity downgrades, and may be completely neglected in the future. In the case study of Lodi, productive capacity is also the major indicator of soil quality considering the fact that i) land take in the Province affects mainly agricultural fields, ii) agricultural land has a high suitability for productivity capacity because of the high fertility of such soils.

The aim of a composite indicator is to overcome the limitations of the traditional quantitative approaches of LUC analysis, thus leading research to a reflection on (1) the consistency of LUC analysis itself and (2) the possibility to keep ES evaluation within a single indicator.

Following the methodology proposed in the "Handbook on constructing composite indicators: methodology and user guide" (Giovannini, *et al*. 2008), targets are outlined as guide-

lines for the preliminary evaluation of the indicator's output[7].
After a GIS selection of land-take clusters in the Province of Lodi (years 1999 – 2007), an overlay of three maps was realized: (1) the selection of land-take polygons, (2) the evaluation of the sealing degree on selected land-take clusters, (3) the evaluation of Land Capability values on selected land-take clusters.
The first GIS output (1) has been developed within four operations:

- the topologic overlay between land use databases in two-time threshold DUSAF[8] (1999 – 2007);
- the creation of a new field ("flusso") where land use changes are reported at the second level of the legend;
- the selection of "land take" flows, composed by the variation of classes 2, 3, 4 and 5 changed into class 1 between 1999 and 2007;
- the creation of a 10-meter buffer on "land take" areas to correct some imprecisions among different databases.

The second and third GIS output (2) (3) have been developed within the following operations:

- the clip of DB top layers with "land take" buffered areas of DUSAF;
- the clip of LCC layers with "land take" buffered areas of DUSAF;
- the union (intersection) of clipped databases (DB top and LCC) with buffered areas of DUSAF;
- the assignment of specific values to each single attribute.

In particular, the development of last point requires-a reclassification and a sum of values for each registered phenomena: land take, sealing, downgrade of LCC.
The selected variables were ranked (from 0 to 5) on the base of the tables in the following report.
The overlay of the three thematic maps (intersection tools in ArcMap 10) has generated a single map where in each land-use cluster the sum of the three values is being reported[9].

The score of the final map, representing the sum of each registered impact, ranges from a maximum of 15 (summing single impact 5+5+5 per cluster cell) to a minimum of 0. The overlaying process is shown in the following figure (see figure 3).

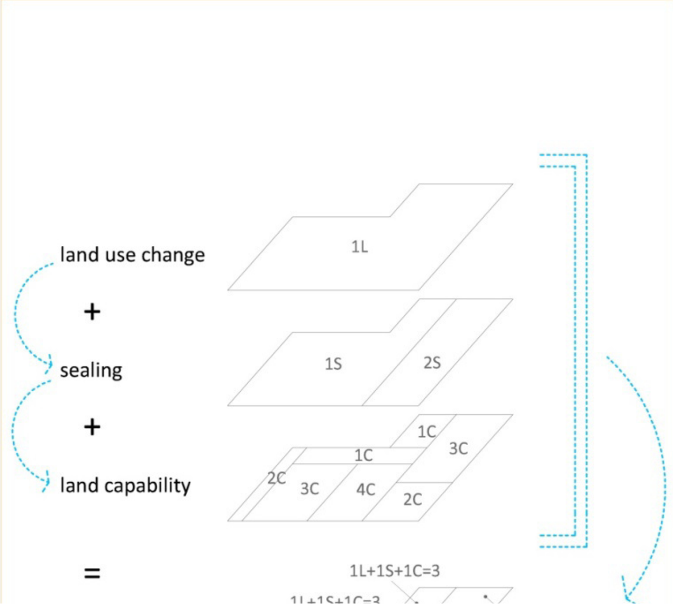

Figure 3 – Composite value as the sum of the single layer's value.

The composite indicator called "Land Take Impact" (LTI) is composed by the average impact per m^2 of each selected cluster.
The formula is as follows:

$$LT1= \frac{\sum_{n=1}^{\infty} (\text{sq m*valtot})}{(\text{sq m tot})}$$

Where "valtot" is the composite value registered by the sum of the different impacts on land take clusters.
LTI can be both referred to provincial (in a greater degree) and municipal level. In the first case LTI represents the average impact of land take to the total land area involved in a process of artificialization in the Province. In the second case it is referred to a single municipality. Further both impacts (provincial and municipal) will be observed; in the latter case a comparative analysis between municipalities is shown. Within GIS operations, LTI was grouped in three ranges of values: from 0 to 6 (low impact), from 7 to 10 (medium impact), from 11 to 15 (high impact)[10].

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7. four targets are mentioned in the Handbook:
- the creation of an indicator based on a scientifically grounded framework of the single variables; the evaluation of single variable values within an uniform ranking;
- the preliminary assessment of the correlation between selected variables;
- the absence of "discretization" and the maintenance of single land use clusters using a high-precision land use/cover database.

8. DUSAF is the regional land use/cover database in Lombardy. It is free and downloadable from the website of geoportal (http://www.cartografia.regione.lombardia.it/riregisdownload/). It was used to select the poligons where land take occurred during the observed period.

9. A cluster is the minimum geometric unit of land take polygons. For example, if a portion of soils is subjected to a land use variation (from agricultural land to urban land) then the "land take" area is composed by different clusters of impacts. If a new industrial plot of 1 ha is created, the part which is completely covered by streets or settlements (3,000 sq m) is subjected to high impact due to complete impermeabilization of covers, while a green parking area (7,000 sq m) which could be permeable at 50% could have a minor environmental impact. In this case in 1 ha of registered land take two different clusters of impact are recognized: 3,000 sq m high impact, 7,000 sq m medium impact. In the case, previously mentioned in the text, the average "clusterization" per hectar is equal to 23.9 cluster/ha

10. As introduced in the previous note this categorization is made using the layer properties on the new shapefile called LTI. The cat-

Table 3 – Ranking of Land Use Change flows between 1999 and 2007.

Land take (flows)	***Values (1 to 5)***
21 to 11 from arable land to urban fabric	***4***
21 to 12 from arable land to industrial, commercial and transport unit	***4***
21 to 13 from arable land to mine, dump and construction sites	***5***
21 to 14 from arable land to artificial, non agricultural vegetated areas	***0***
22 to 12 from permanent crops to industrial, commercial and transport unit	***5***
22 to 13 from permanent crops to mine, dump and construction sites	***5***
22 to 14 from permanent crops to artificial, non agricultural vegetated areas	***2***
23 to 11 from pastures to urban fabric	***4***
23 to 12 from pastures to industrial, commercial and transport unit	***4***
23 to 13 from pastures to mine, dump and construction sites	***5***
23 to 14 from pastures to artificial, non agricultural vegetated areas	***1***
31 to 11 from forest to urban fabric	***5***
31 to 12 from forest to industrial, commercial and transport unit	***5***
31 to 13 from forest to mine, dump and construction sites	***5***
31 to 14 from forest to artificial, non agricultural vegetated areas	***3***
32 to 11 from scrub and/or herbaceous vegetation association to urban fabric	***5***
32 to 12 from scrub and/or herbaceous vegetation association to industrial, commercial and transport unit	***5***
32 to 13 from scrub and/or herbaceous vegetation association to mine, dump and construction sites	***5***
32 to 14 from scrub and/or herbaceous vegetation association to artificial, non agricultural vegetated areas	***3***
33 to 13 from open spaces with little or no vegetation to mine, dump and construction sites	***5***
41 to 14 from inland wetlands to artificial, non agricultural vegetated areas	***3***
51 to 12 from inland waters to industrial, commercial and transport unit	***5***

Table 4 – Ranking of sealing degree.

Sealing	***Values (1 to 5)***
DBT - A010101 - Area of vehicular traffic	***5***
DBT - A010102 - Area of pedestrian circulation	***5***
DBT - A010103 - Area bicycle circulation	***5***
DBT - A010105 – Secondary roads	***2***
DBT - A010201 - Railway area	***4***
DBT - A020102 - Building	***5***
DBT - A020201 – Industrial platform	***5***
DBT - A020202 – Monumental artifact	***4***
DBT - A020203 – Artificial manufact	***5***
DBT - A020204 – Sports camps	***3***
DBT - A020206 - Ground impermeable cover	***5***
DBT - A020207 - Electricity pole	***1***
DBT - A020210 - Wall divisions	***5***
DBT - A050303 - Excavation area or dump	***4***
DBT - A050304 - Transformation area	***3***
DBT - A060401 - Green area and parks	***1***
DBT - A060105 - Pasture	***0***
DBT - A060106 – Arable land	***0***
DBT - A020401 - Retaining wall	***2***
DBT - A020502 - Embankments	***0***
DBT - A050393 - Open space with no vegetation	***0***
DBT - A060101 - Forests	***0***
DBT - A060102 – Scrub and/or herbaceous vegetation association	***0***
DBT - A060104 - Open space temporarily with no vegetation	***0***
DBT - A040103 – Artificial basin	***0***

Table 5 – Ranking of Land Capability degradation.

Land Capability Classification	***Values (1 to 5)***
1	***5***
2	***4***
3	***3***
4	***2***
5	***1***

The resulting distribution is as follows:

- 87.2 ha of soils are subjected to a low impact, corresponding to values included between 0 and 6, thus to 6.3% of the total amount of land take registered between 1999 and 2007 in the Province of Lodi;
- 551.9 ha of soils are subjected to a medium impact, corresponding to values included between 7 and 10, thus to 40.3% of the total amount of land take registered between 1999 and 2007 in the Province of Lodi. This means that the variation of each single land-use cluster is characterized by medium levels of land-use transformations, medium levels of sealing and medium levels of capability, but a medium impact can be also composed by a low value in terms of land-use transition but high values of sealing and loss of capability;
- 733.5 ha of soils are subjected to a high impact, corresponding to values included between 11 and 15, thus to 53.4% of the total amount of land take registered between 1999 and 2007 in the Province of Lodi. This means that the variation of each single land-use cluster is characterized by medium or high levels of land-use transformations, sealing and loss of capability.

This preliminary classification serves to provide adequate information about the process of urbanization occurred in the Lodi Province, which was equated to 1,372.6 hectares between 1999 and 2007.

The absolute majority of clusters analyzed is subjected to relevant (high) impacts in terms of composite effects on soil.

The analysis of the main components has been implemented by testing a few linear combinations of the original data. Once the three selected variables were ranked from 0 to 5, a correlation index between them was calculated. A linear correlation has been issued between the vertical values of each cluster cell.

In the construction of composite indicators a lack of correlation among the main components is a useful property: it indicates that the main components are measuring different "statistical dimensions" of the data. Otherwise when single variables are accounted as highly correlated the new indicator suffers from inconsistency. In the case described low correlations between the three selected variables were detected.

In fact, the analysis of the correlation among the values (land-use change, sealing and capability classification, table 6 right part) demonstrates how independent the three variables are: all the correlation coefficients are not significant (0.03 is the correlation index between the sealing values and the capability ones; 0.02 is the correlation index between the LUC values and the capability ones).

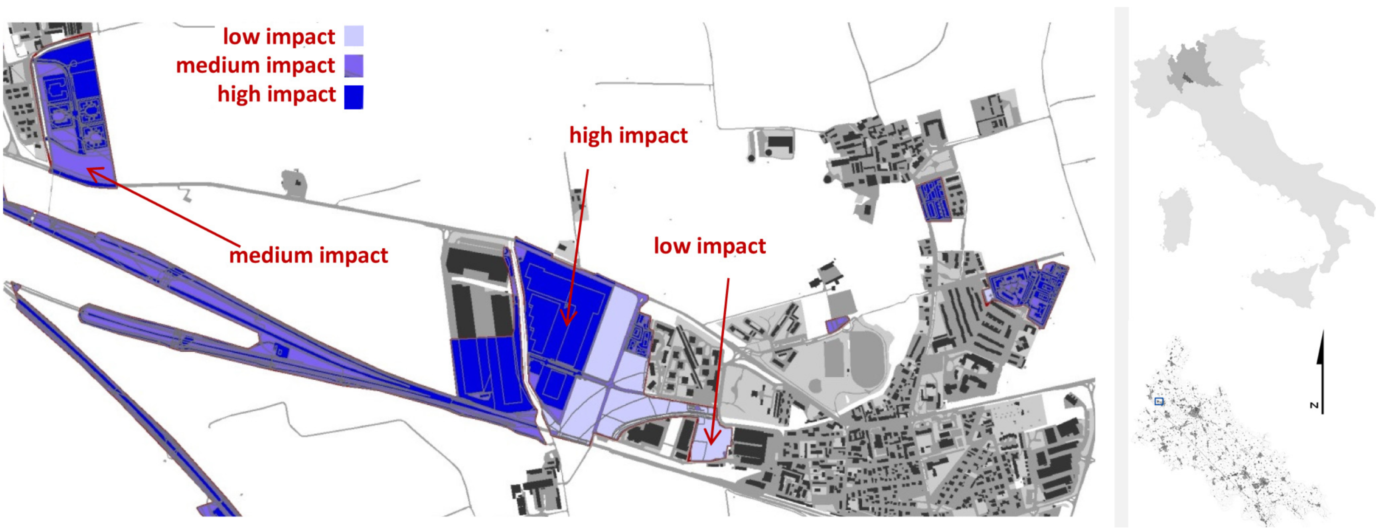

Figure 4 – LTI distribution of impacts (extract of Lodi's Province).

egorization is made using three classes ranged with a manual classification: low impact 0-6, medium impact 7-10, high impact 11-15.

Table 6 – Correlation between selected variables.

cluster	polygon	flusso	value_LUC	value_sealing	value_LCC	valtot		LUV and sealing	LUC and LCC	sealing and LCC
0	189711	2111	4	5	4	13		0,01	0,02	0,03
1	189711	2111	4	5	4	13				
2	189711	2111	4	5	4	13				
3	189711	2111	4	1	4	9				
4	189711	2111	4	1	4	9				
5	189711	2111	4	0	4	8				
6	189711	2111	4	0	4	8				
7	189711	2111	4	0	4	8				
8	189711	2111	4	0	4	8				
9	189739	2112	4	5	4	13				
10	189739	2112	4	5	4	13				
11	189739	2112	4	5	4	13				
12	189739	2112	4	5	4	13				
13	189739	2112	4	0	4	8				
14	189739	2112	4	0	4	8				
15	189739	2112	4	0	4	8				
16	189739	2112	4	0	4	8				
17	189739	2112	4	2	4	10				
18	188236	2112	4	5	4	13				
20	188236	2112	4	5	4	13				
20	188236	2112	4	5	4	13				

3. Results and Discussion

The analysis of LTI index indicates that, in a total of 32,810 selected clusters in the Province of Lodi, the impact includes values from 0/15 until to 15/15. Approximately 10,000 m^2 of soils are not subjected to any impact (even if those soils are subjected to land-take processes), and more than 280,000 m^2 of soil are subjected to a maximum impact. In the latter case most of the soils are composed by the infrastructure sediment constructed in agricultural areas with high values of capability: this specific land use variation implies high impermeabilization and high loss of agricultural productivity.
The average LTI in the Province of Lodi is 11/15 (10.65), corresponding to a medium/high level, which means that land take in Lodi normally occurs with a relevant impact.
The disaggregated analysis of LTI distribution for each single municipality indicates that the most relevant impact has occurred neither along the High Speed train corridor (built in the early 2000s) nor inside the main urban areas of the Province: the Municipalities of Lodi, Codogno and Casalpusterlengo.
This represents something unpredicted, if compared with traditional LUC analysis which addresses major impact of Land Take to highly populated municipality.
Marginal and small Municipalities such as Zelo Buon Persico, Mulazzano, Cervignano d'Adda, Maleo and others that are not included in the historical axes of settlement development are subjected to a high impact in terms of the environmental effects of land take.

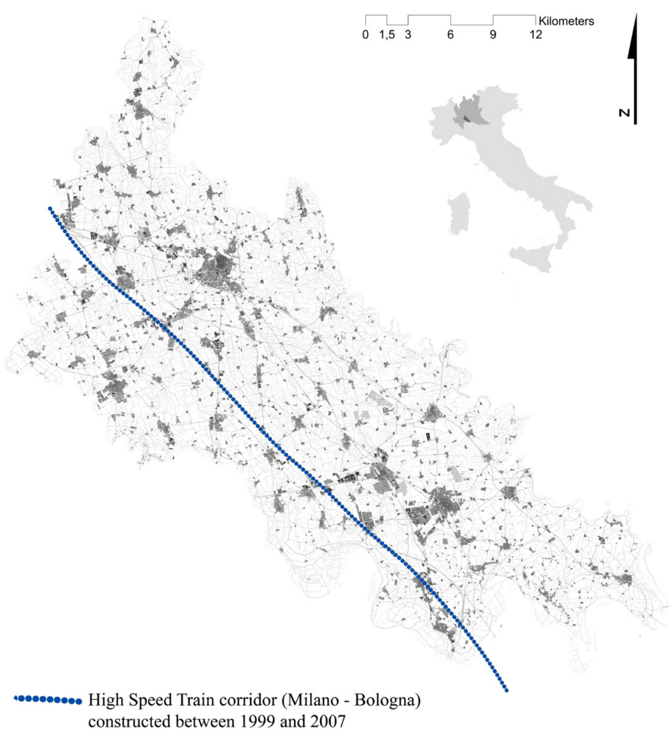

Figure 5 – High Speed train corridor.

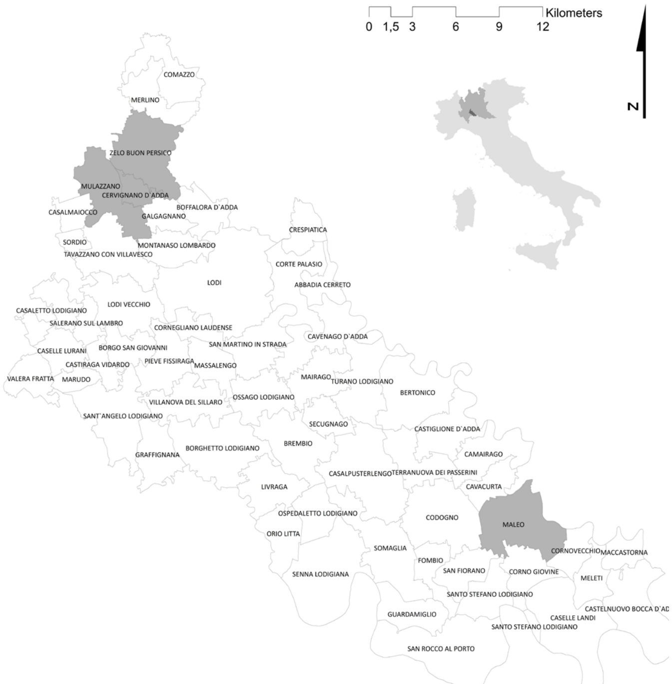

Figure 6 – Highest LTI distribution.

In addition to this, the independence of the two variables "land take" and "LTI" is stressed by the correlation index between the two variables, which equals 0.1.

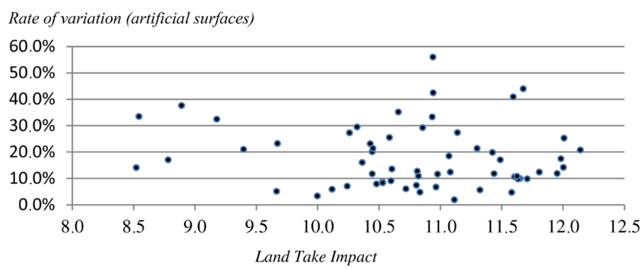

Figure 7 – Relation between impact (LTI) and quantity of land take (variation class 1).

As shown in Figure 7, the distribution of "variation of artificial surfaces" and "LTI" at municipal level does not show any clear relation between variables. The dots distribution is nonlinear, and a flattening of point on 10.0% (y axes) is recognizable where high impact occurs (between 10.5 and 12.0 values of LTI). This confirms the fact that municipalities with larger amounts of registered land take (in quantitative terms) do not correspond to the municipalities where the impact is high, and on the contrary, it is possible to confirm that where high impacts took place a low rate of variation of artificial surfaces is registered. In other terms, the graph demonstrates that the cumulative environmental impact caused by land take on soil is not represented by the simple increase of artificial surface but rather by the specific typology of land use change that has occurred. This, in turn, implies that, with specific regard to land-take phenomena, traditional LUC analysis is inefficient in identifying both the morphological problem (intended as the characterization of settlements in terms of density, continuity, concentration, clustering, centrality, nuclearity) and the environmental one.

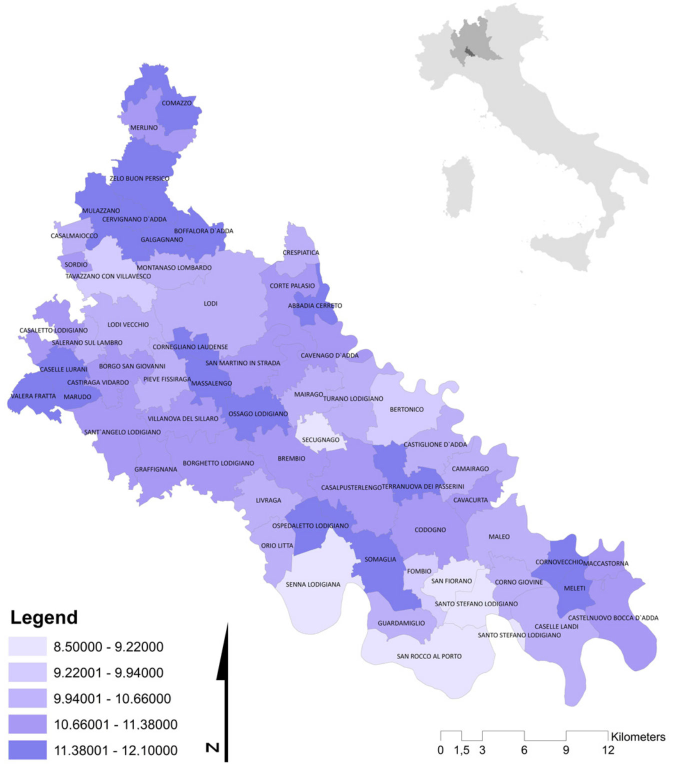

Figure 8 – Territorial distribution of LTI.

A second correlation index between population and LTI at municipal level shows the absence of significant relations between these variables as well (-0.03).

The graph in figure 9 shows a visible flattening of points along the average dimension of population (5,000 inhabitants, corresponding to more than half a percent of the total municipalities in Italy). Nevertheless the distribution confirms that the four less populated Municipalities are subjected to the greatest land take impacts, therefore proving that smaller municipalities are characterized by higher impacts. On the contrary, densely populated municipalities (the one between 10 and 20 thousand inhabitants, including the main municipality of Lodi which represents an outlier in the figure because of its overpopulated territory, more than 40 thousand inhabitants) are flattened between 10.0 and 11.0 level of LTI.

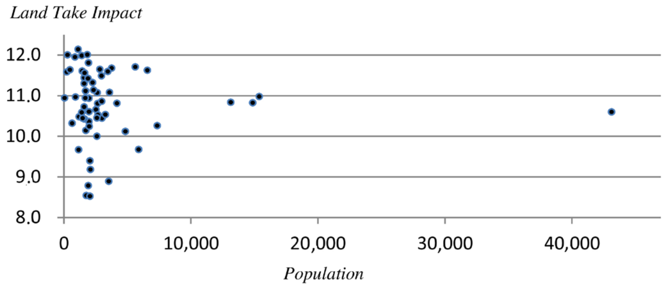

Figure 9 – Relation between inhabitants and LTI.

The first results demonstrate an incoherence in analyzing specific land-use patterns at local scale (phase??) as the traditional approach to land-use variation LUC is consistent in supporting analyses at aggregated scale. LUC analysis turns out to be inadequate for an in-depth evaluation of land take processes and their impact on the ES that can be delivered to these areas. Therefore the employment of the proposed indicator (LTI) for a multifunctional representation of land take is proposed as a methodological alternative (Helming, *et al*. 2011). The question, in fact, is how to address right policies for land take limitations according to the "multidimensional" aspect of the phenomena?

Based on the additional information provided by LTI, an operation of reclassification of values has been carried out for the following indicators: land take (hectares), percentage of artificial surfaces (%), increase rate of artificial surfaces (%), artificial footprint per capita (square meters of artificial surface per capita), LTI (values ranging from 1 to 15).

In the process of pattern interpretation the specific information provided by each indicator is taken into account. In order to visualize the different dimensions of land take, pentagonal graphs (spider chart) were used: the vertices of the figure represent the selected variables for a multidimensional representation of land-take effects.

As for LTI construction, the representation of spider charts, shown below, tends to hold together disjoint variables. We aimed to give an adequate representation of the "multidimensional" aspect driven by land take phenomena. The increase of artificial surface (which constitutes a pressure variable) is not directly dependent on the percentage of artificial surface (which is a state variable), and as demonstrated, LTI is not corresponding to the highest value of land take.

The most representative spider charts are reported and commented on below.

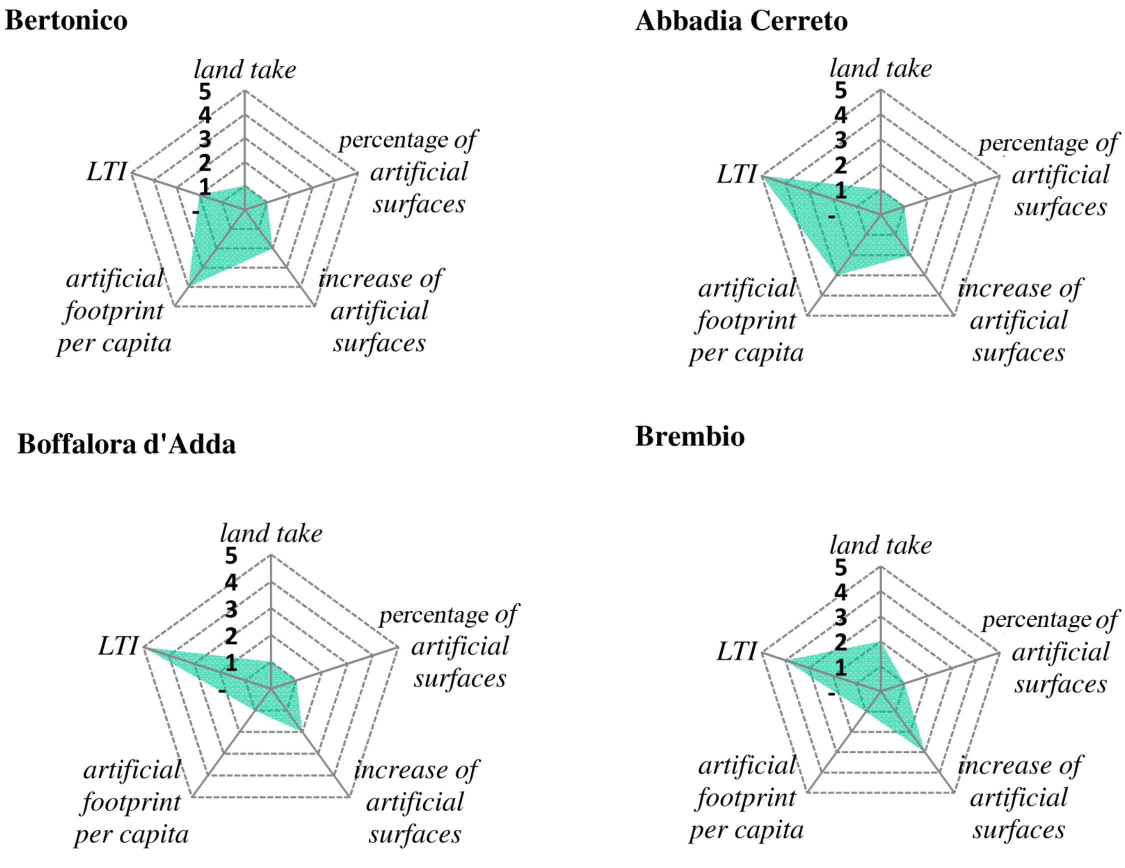

Figure 10 – Multidimensional analysis of land take.

3.1 The multidimensional levels of land take: an interpretation of the patterns

The pentagonal area covered by the spider graph represents the multidimensional levels of land take. An overview of all the graphs demonstrates the heterogeneity of land take process in different municipalities.

This type of representation provides an east-reading information which facilitates understanding that specific strategies for reducing the global impact of land take need to be considered. For example, it is shown how some patterns are balanced (defined as "centered"[11]), and others unbalanced ("cusped"[12]). The more centered the patterns, the more generally acceptable are the available options to limit, mitigate or compensate soil sealing. The options to reduce the impact of land take become more specific and limited the more unbalanced the patterns are.

The most representative patterns of land take are introduced and discussed further. For each pattern, a list of options on how to limit, mitigate or compensate soil sealing, based on the EC Guidelines(E. European Commission, Guidelines on best practicies to limit, mitigate or compensate soil sealing 2012) , is proposed.

Future options for the limitation:

- improving the quality of life in large urban areas (L1);
- strengthening public transport infrastructures (L2);
- increasing protection of soil at national level (L3);
- engaging in the integrated management of the stock of office buildings in cities (L4);
- enabling or strengthening the cooperation of neighboring local authorities on the development of commercial areas (L5);
- creating incentives directed at land recycling instead of developing new land (L6);
- taxing secondary residences (L7);
- raising the awareness of decision makers (L8);
- developing a philosophy centered on using land economically (L9);
- establishing funding programs as a "start-up" incentive for a more sustainable land management (L10;
- using cost calculator programs to define the inner-urban development potential (L11)

Future options for the mitigation:

- using permeable materials and surfaces (M1);
- developing green infrastructure (M2);
- incentivizing natural harvesting systems (M3)

Future options for the compensation:

- the reuse of urban topsoil (C1);
- the implementation of de-sealing techniques (soil recovery) (C2);
- the use of trading development certificates (C3);
- the definition of sealing fees (C4)

Below some land take patterns are reported and analytically categorized.

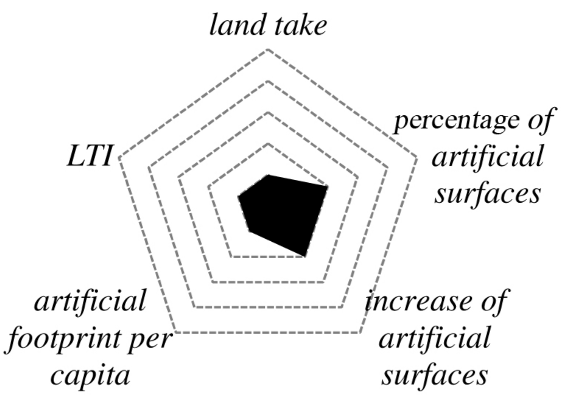

Figure 11 – Centered limited, low-covered area.

The pattern in figure 11 displays a low-covered area, meaning that the multidimensional levels of land take are limited: here low land take is detected, with a modest augmentation in the increase of artificial surfaces and a modest percentage of artificial covers.

As LTI demonstrates, the land take has a low impact on covers. Therefore measures L6, L7, L8, M1 and C1 are sufficient to reduce the rate and impact of land take for this specific pattern.

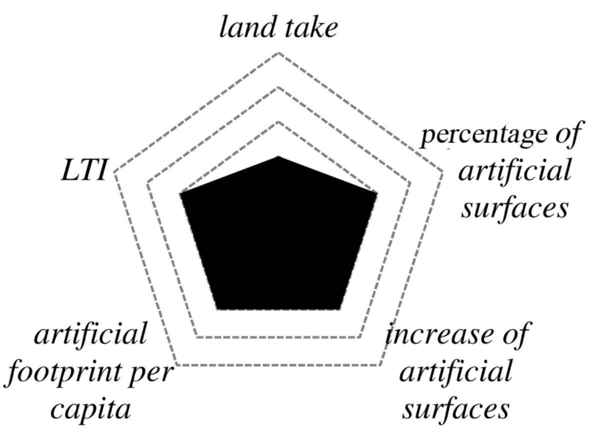

Figure 12 – Centered moderated, medium-covered area.

The pattern in figure 12 displays a medium-covered area wherein specific measures must be taken.

The level of land take in this case is not very high but all the

11. It means that the pentagonal coloured area of the chart is approximately equally distributed around the chart centre.

12. It means that the pentagonal coloured area of the chart is not equally distributed around the chart centre and forms specific axes or cusps.

other indicators illustrate a process of consistent augmenting of artificial surfaces with a medium artificial footprint per person and a medium impact of land take.
In this case a mixed use of limitative, mitigative and compensative measures helps to reduce the speed and impacts of land take. L2, L6, L7, L8, L9, M1 and C1 are required.

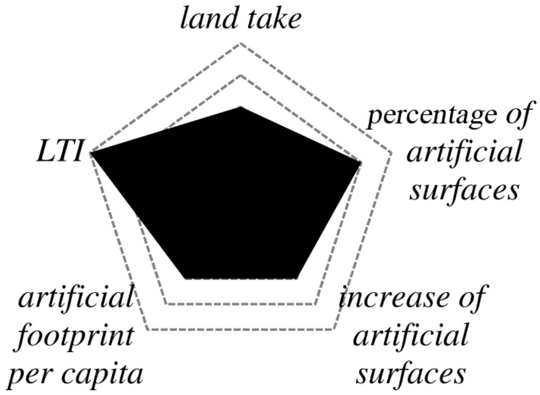

Figure 13 – Centered highly affected, highly-covered area.

The pattern in figure 13 displays a large amount of covered area. This suggesting that land take is problematic. Even if land take is not high, this pattern presents a consistent value of the existing and increasing artificial surfaces, and a consistent footprint with a high LTI: this means that the reduction of land take in this case is less important than the mitigation and compensation of its effect. As a result L6, L7, L8 are integrated by M1, M2, M3, C1, C2 and C4.

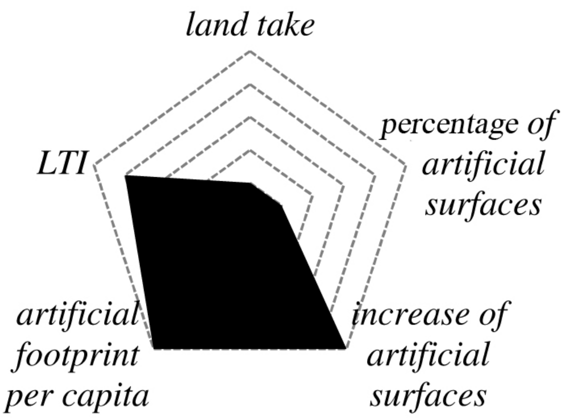

Figure 14 – Uncentered highly affected, highly-covered area.

The pattern in figure 14 is largely covered but unbalanced. This indicates that land take is problematic for specific aspects. In particular, this pattern demonstrates an important augmentation in artificial surfaces, a high artificial footprint and LTI, despite a low land take. This is the case of small municipalities where land take always has a high impact. In this case reduction is important, but mitigation and compensation are highly recommended. L6, L7, L8, M1, M2, C1, C2 and C4 are required.

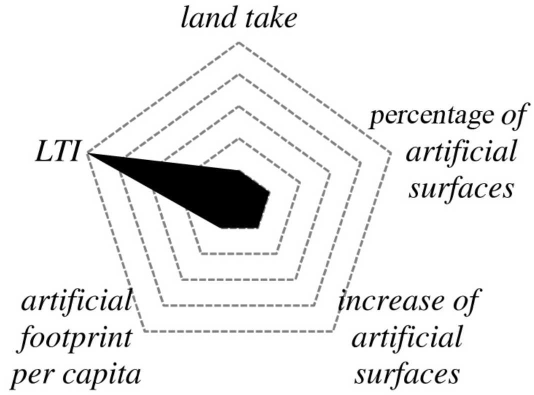

Figure 15 – Unbalanced 1-cusp, low-covered area.

The pattern in figure 15 displays a low-covered area but presents a visible cusp, which means that it is affected by a specific dimension of land take. This pattern shows that specific measures, rather than general policies, are required. In this case LTI is high even in the presence of a low land take, footprint and artificial surfaces. In order to reduce impacts, mostly mitigation measures should be adopted. L6, L8, M1, M2, M3, C1 are suggested.

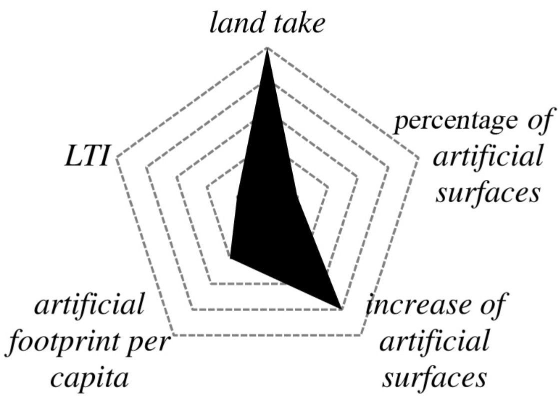

Figure 16 – Unbalanced 2-cusp, medium-covered area.

The pattern in figure 16 displays a medium-covered area and forms a particular shape: a double cusp. This implies that these two particular aspects of land take are more relevant than others. In this case land take and the increase of artificial surfaces are affecting land-use change with low impacts and with a medium footprint per capita. Consequently specific limitative options have to be considered. L1, L2, L4, L6, L7, L8, L9, M1, C1, C4 are required.

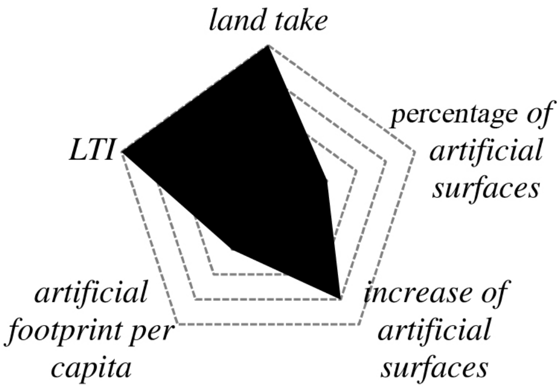

Figure 17 – Unbalanced-3 cusp, highly-covered area.

The pattern in figure 17 displays a highly-covered area, where the three spreading cusps, suggesting its problematic nature, represent specific aspects of land take. This case demonstrates a high land take, with an important increase of artificial areas even if the percentage of artificial area is low. Here the land take is affected by a high level of impact.

In this case an integrated approach of reduction, mitigation and compensation has to be adopted. Therefore L1, L2, L6, L7, L8, L9, M1, M2, C1, C3, C4 are suggested.

4. Conclusions

Despite a constant demand for urgent intervention and regulation that will tackle on the incessant consumption of open space calculated at an aggregated scale, it seems that the problems of improvement of particular land-use development patterns have not yet been properly addressed. Even if analysis on land take is becoming much more significant, less success cases of land take reduction is registered. Land use management and land government practices experience weak connection with scientific studies and indicators.

A simple contextualization of the analysis on land use and land cover give us simple but clear indications: traditional tools for land use/cover analysis are not adequate for the evaluation of impacts on ES and are insufficient to steer local policies for land conservation. The approach presented in our study, despite being preliminary and applicable mainly at regional scale, allows the introduction of a more global evaluation of the impact of land take on ES, with particular attention to the capability of food and biomass production.

In order to implement soil sealing guidelines and activate a sustainable soil and land governance, shifting from attributes to processes, a multidisciplinary approach is needed to bridge the gap between general, theoretical targets (e.g. land-take limitation) and the development of specific patterns of land-use management at local scale.

Some limitations of this approach should be mentioned: within our framework, some of the variables selected for representing the cumulative impact of land take (spider charts) are highly correlated, providing a high degree of redundant information. The need to overpass the simplistic approach of LUC analysis and to provide better information and more comprehensive data will enable policy and decision makers to activate right prescriptions, limitations or regulation for land use management. The study has generated a representation of trade-off between different “aspects” of land take, this information provides valuable support to planning, by narrowing some qualitative information for potential decisions.

The detailed analysis in the Province of Lodi shows that in the context of a highly developed informative system it is possible to incorporate different attributes and information on land-use change and covers with other high-precision databases.

The research also demonstrates that a complete assessment of the land-take process at local scale requires a global evaluation of different soil ecosystem services, and not only the simple accountancy of the land-take area.

As consequence local policies aiming at land-take limitation, mitigation or compensation need then to be supported by multidisciplinary researches and analyses.

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