ISUT model. A composite index to measure the sustainability of the urban transformation

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Abstract. The urban transformation is the result of several decisions made in a variety of temporal and spatial scales, which concern the field of urban planning regarding the location of buildings and activities, position of transport networks, that in fact are more persistent (Morris, 1994). The urban transformation generates environmental impacts in terms of soil sealing, energy consumption and urban heat island (Ewing, Rong, 2008), which result in consequences on stormwater runoff, on raising the temperature and increasing of CO_2 emissions. From a representation of the state of the art, the present paper defines a composite index called ISUT (index of sustainability of the urban intervention). The ISUT covers all the essential components of the urban design which condition the energy balance equation (Parham and Fariborz, 2010). The composite index value is used to propose better strategies to guide the development of local area plans in conjunction with the City's Plan using an easy data-set which derives from the knowledge of the territory, which is usually already acquired for urban planning tools on a municipal basis.

150-200 parole

1 Introduction

Cities represents a dramatic manifestation of human activities on environment (Ridd, 1995). This artificial organism degrades natural habitats, simplifies species compositions, interrupts hydraulic systems and modifies energetic flows (Alberti, 2005), with health and socio-economic consequences in the long term too. In urban planning, the renewed interest in the environmental-energy sustainability criteria is relatively new, likewise the recent scientific approaches of coding and logging of procedures, parameters and sustainability indicators used in this area of study (Jaeger, et.al., 2010; De Wilde and Van Den Dobbelsteen 2004; Schwarz, 2010). It is quite obvious how essential is the alignment between the architectural design and sustainable urban design, because strategical choices, in matter of regulation and urban planning, if not well calibrated on the sustainability, could make partially ineffective the results in the area, also if those are modeled on principles of environmental sustainability and respectful of the parameters of any protocols (IISBE, 2012).

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The urban plans, generally, have little consideration of environmental aspects apart, in fact, they provide just some reference, like, for example, to the obligation to respect permeability thresholds.

Sustainable urban development is a broad and multi-dimensional concept, a theoretical framework is needed to deal with what is meant by sustainability of the urban project and which kind of tools should be developed for the evaluation (Carraro et al., 2009).

The impact of the urban structure and therefore the actions of urban transformation on the environmental components has a formal expression in the surface energy balance equation (Parham and Fariborz, 2010; Stull, 1988). For a surface energy in equilibrium it is valid relation the Following:

$$Rn = Rg\ (1\text{-}A)\text{-}RL = QG+QH+QE \qquad (1)$$

which expresses how energy inputs, that is the net radiation (Rn), are used to heat the air in contact with the ground (triggering a flow of sensible heat QH); to evaporate, or transpire water, if there are any plants, (triggering a flow of latent heat, QE); to heat the interior of the soil (triggering a flow of heat in the soil, QG). Rn is the result of the balance between incoming global solar radiation (Rg) net of albedo (A), and the emission of long wave radiation at the earth's surface (RL); greenhouse gases, along with clouds and atmospheric dust, act on RL term, partly intercepting and re-radiating it to the ground. Thereby they limit the cooling of the earth's surface by radiation into the space.

The presence of urban area changes the terms of the energy balance and introduces two new terms (Oke, 1987); Oke et .al. 1991), the anthropogenic heat flow QF, and the flow of heat stored in the urban structure ΔQS .

QF is an additional source of heat that comes from human activities and the energy they involve, such as traffic, heating, combustion industrial, production and consumption of electricity.

ΔQS depends on the materials and geometry of the urban context, but above all on the density of buildings.

As a first approximation ΔQS can be expressed as a function of green spaces and built-up areas (Oke 1981).

But even QF, indirectly, is a function of the built-up areas, as urban areas increase with increasing human activities. Overall, therefore, the urban areas compared to country areas are rich in energy and this imbalance is even more fragile because of extra heat sources (Gerundo et.al., 2012).

Through the analysis and the considerations about the experiences as a system, it’s been developed a new model that faces the urban planning and projects in an integrated and organic way that includes the different impacts.

The aim of this contribution is the construction of an index, defined of sustainability of the urban transformation (ISUT).

This index allows us to control, in a quantitative way, the sustainability of both the individual building project or a sub-urban plan project to implement, likewise also to check, on the existing urban structure, the efficiency of possible adaptations, energy and environmental, of existing settlements, however always desirable. This method allows investigating the impact of human development on the natural environment through a model that evaluates the direct and indirect effects on urban ecosystem through some indicators measured on the specification of the context. This method monitors the distribution and organization of surfaces, seeking the protection of soil, of water, of air and guarantees a better life's quality for the users of urban spaces (Gerundo et.al, 2012).

Using, in fact, a set of selected indicators, it was assumed to combine these linearly in a sustainability index that supports the processes of territorial government at the urban scale, both in the analysis of the existing, both in the design and verification. The screening at the base of the construction of ISUT index has allowed to expand the macro-fields of study, to extract an appropriate set of indicators of sustainability in urban areas. Moreover, it lets to define a framework that takes the form in a model of eco-sustainable urban regulations, possibly to be included in the instrument of municipal planning building rules.

2 Metodology

The methodological framework proposed, consists of the two following macro-phases:

- macrophase 1: selection of a set of indicators to measure the influence of the urban structure on ΔQS and QF;
- macrophase 2: construction of the ISUT relative to each minimum unit, in which the urban structure has been split.

The proposed methodology requires a level of knowledge of the area, ordinarily taken for the preparation of an instrument of structural urban planning, on a municipal basis. Specifically, for its proper application, the methodology requires a minimum level of information consisting of a cartographic support of vector type at a 1: 2000 scale, made by an aerial digital survey. This last one has associated an alpha-numerical database containing information about the volume and floor areas of individual buildings, as well as information about the materials and the prevailing urban land use.

2.2 Macrophase 1

On the first phase, according to categories of green spaces (G) and built-up area (B) of the urban structure, are identified the following components:

- vegetation;
- permeability of soil;
- materials of urban construction;
- urban morphology.

Afterwards, a set of indicators have been selected according to the available knowledge, which has allowed us to measure the morphometric characteristics of the urban settlements that affect QF and ΔQS respectively (Tab.1).

Dopo aver selezionato lo stile portare "Table 2" in grassetto. Così anche per le Figure

Table 1. Indicators selected

Cat.	Energy Factors		Indicator	Formula	Description
G	ΔQS	I1	Coefficient of occupation of the vegetable land (Cvo)	$\lvert(Salb * Halb) + (Sav * Hav)\rvert / St$	Salb = area covered by trees Halb = tree height Sav = occupied area by lower beds and green roof Hav = height of flower beds St = land area
	ΔQS		Permeability ratio (Rp)	Sp/St	Sp = the sum of the permeable areas exposed to rain water, considered according to their degree of permeability St = land area
B	ΔQS; QF	I2	Average reflection coefficient (ICrm)	∑Ci*Ai/∑ Aì	Ci = coefficient or reflection of a given material; Ai =surface area of a specific material.
	ΔQS; QF	I3	Index of local volumetric density (Iv)	V/St	V= sum of the volumes of buildings St = land area
	QF	I4	Thermal dispersion index (IDt)	S/Vh	S= dispersive surface area Vh= heated volume

In order to consider the presence of vegetation on a land area (Sf) or territorial area (St) (Saito et.al, 1991 Honjo and Takakura 1991), as in the literature, we refer to the coefficient of vegetation occupation (Cvo) (Arnofi and Filpa, 2000).

The Cvo is an indicator that aims to assist the other parameters, related to built-area; this indicator is a measure of the presence of vegetation, and it is used to approximate the visual perception of different structures of urban green, also depending on the permeability of the soil and its water retention.

The potential direct supply of the aquifer is taken into account through the ratio between the sum of the individual surfaces exposed to rainwater, considered according to their degree of permeability measured as the inverse of the runoff coefficient of the material of which is built the i-th permeable surface. Both the indicators are linearly combined in an overall indicator (I1).

The average reflection coefficient, of all the surfaces exposed to radiation related to the building or urban project, is used to calculate the albedo factor control's indicator for urban construction materials (I2), considering the totality of the building structures on single lot or isolated.

The application of this indicator, requires the identification of the type of material its extension and the definition of its reflection coefficient.

As regards the characterization of the existing urban structure, for the detection of different types of material, it is used, or a direct survey, through the interpretation of photographic survey, or by using the potential of the observation's technology by thermal remote sensing.

In the case of a urban project, it is imposed, during the design phase, the adoption of materials with known reflection coefficient in order to check in advance the Cm of the project.

As it regards the urban morphology component we take into account morphological indicators and the indicator related to passive energy efficiency of the urban project. About the morphology aspects, it has considered significant, in order to automate the procedure in GIS environment, the choice of an indicator of local volumetric density (I3), as ratio between of the sum of the volumes of the buildings and the reference area. This indicator, on the same reference area, takes into account both the effects of the distance between the buildings, both the ratio of unobstructed view. This assumption loses the information related to the orientation of buildings, however, the calculation of this indicator, extended the block or to the lot, would require strictly to consider also the phenomenon of the correlated shadows, difficult to model in GIS environment. About the energy aspects, attention is paid on the compactness of the building (cfr. Dlgs 192/05, Dlgs 311/06, Dir 2002/91/CE, energy performance of buildings). Specifically we consider the ratio S/V (I4) between the volume and the heated dispersing surface, which provides positive information, as lower is the resulting value. Strictly should be considered also the orientation with respect of the solar path (cfr. Regione Campania, Dgr 659/07 "Obiettivo D1", in this local law it is taken, as the optimum arrangement for the buildings, the East-West axis, with decreasing values down to the last corresponding to the angular variation of +/- 45 ° respect to the ideal).

2.2 Macrophase 2

In the second phase of the methodological approach, we proceed to synthesize the various indicators, that previously have been described, in a complex index, in order to identify a measure that enables us to monitor, in an expeditious way, the energetic and environmental outcomes of urban transformation (Fig.1).

First, we have proceeded with the normalization of the various selected indicators. The procedure of normalization is an operation that allows us to make a comparison between the statistical distributions, which are expressed in the respective scales of measurement, in relation to a single scale, that typically includes zero and one. The transformation should not alter the informative content of the initial data. There are several features to provide the above-mentioned transformation. In particular, we have proceeded with the normalization of the selected indicators in order to make comparable the different distributions expressed in the respective scales of measurement. The overall index, ISUT, has obtained by using a linear combination of these indicators.

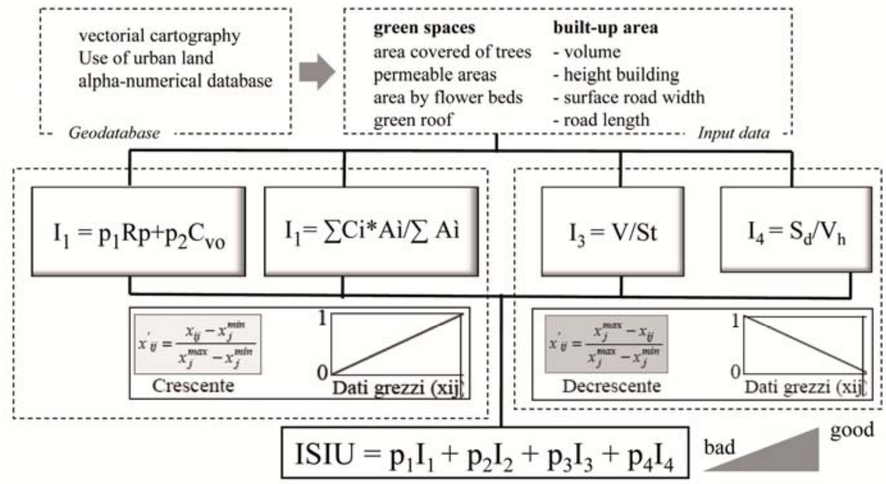

Fig. 1. Methodological framework for the definition of the ISUT

In this case, we refer to the types of changes which maintain the direction of preferences (i.e., the maximum value is the maximum and the minimum is minimal even after processing) for the values of the indicators pertinent to the thematic areas of the vegetal cover of soils and the permeability (I1) materials of urban construction I2 (higher value is better), while we refer to the type which reverses the direction of preferences for the indicators relating to the local volumetric density (I3) and thermal dispersion index (I4) (lower value is better).

This choice is due to the fact that the searched index of sustainability, as a linear combination of those parameters with equal weights, expresses positive outcomes for higher values of the result. In order to read the phenomenon on urban scale, we have made the spatialization of the various indicators for unit of urban structure, in relation to the type of intervention that corresponds to the lot or the block. This series of factor maps let to express the spatial distribution of ISUT, through operations of map algebra.

The map algebra means the use of basic operators, arranged in sequence, in order to solve complex spatial problems. It is substantially similar to an algebraic expression in which the result is a combination of several characteristics. It involves the use of logical and mathematical relationships, in a geographic information system, applied to spatial data, which allows with two or more layers (maps), of similar size, to produce a new layer.

The results of the map algebra operation is a new map which is representative of the spatial variability of the ISUT. We need to estimate the intensity of the phenomenon, through the definition of a suitable scale of values, that must be divided into classes in order to obtain appropriate evaluations. Due to the lack of values of reference, in an absolute sense, for the individual indicators that make up the ISUT, and in order to limit arbitrariness in the definition of the thresholds, we have chosen the method of natural breaks (Jenks, 1969) as method of classification. This method of classification is based on the procedure of optimization that provides the identification of break points in the distribution of the values, given the number of classes.

Through this method the variation of the elements is minimized within each class. In this way the amplitude of the classes varies as a function of the distribution of data within the considered groupings (M. Boffi, 2004).

Defined the number of classes, the concerning thresholds are depending on the only values related to the fabric of settlement that has been analyzed. In this way the methodology is generally valid and applicable to different block, regardless of their extension We have divided the evaluation range into five classes (Carraro et.al, 2009), corresponding to different degrees of intensity, which have been labelled as: very high (VH), high (H), medium (M), low (L) and very low (VL).

3 Case study

This methodology has been tested on the urban fabric of the City of Baiano (Campania, Italy), in order to assess the changes brought about by the choices of urban transformation planned by the Municipal Urban Plan (MUP) (Fig.2).

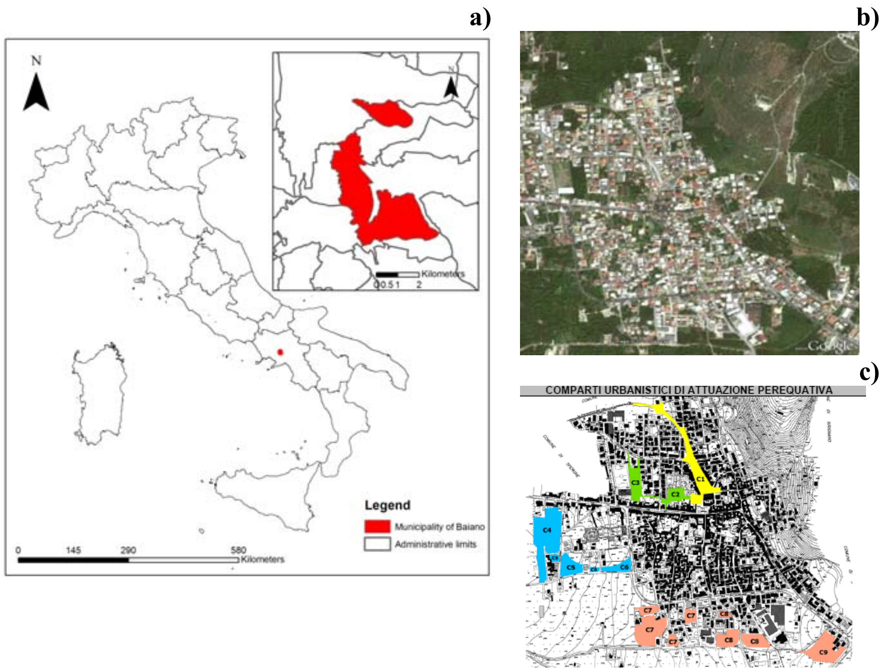

Fig. 2. Geographic location Baiano, Italy (a); base scenario (b); design scenario (c).

3.1 Definition of control indicators in relation with the degree of knowledge

On the first phase of the methodology, that is the measurement of the indicators related to the selected components, we have made several operations of spatial analysis in GIS environment, taking into account the degree of the available knowledge.

Specifically, with reference to the first two components, namely permeability and the vegetation cover of the soil, we have considered appropriate to synthesize, in a single indicator, both information, thus constructing the controlling index of vegetation cover and permeability. First of all, the permeability ratio has been measured. It is intended as the ratio between the unsealed surface and the reference surface that, depending on the considered unit of processing, corresponds to the surface of the lot or of the block. Subsequently, this ratio was increased, through an appropriate multiplier ratio, according to the qualitative component of the specific vegetable cover, classified as a first approximation, in tree or meadow (I1). With reference to the phenomenon of the island of urban heat, in order to construct the index for the control of the albedo factor of the urban construction materials, we have proceeded to a first subdivision of the components of the urban fabric in horizontal and vertical surfaces (I2). The horizontal surfaces include the totality of urban open spaces, which are divided, in turn, in converted areas, in particular road surfaces (asphalt or similar) and squares, and in unsealed surfaces. Moreover the surfaces of the flat roofs of the buildings belong to this category. In addition, we take into account an analysis of the use of urban land for the definition of the average reflection coefficient of such areas, derived from the prevailing law. The vertical surfaces include the totality of the constituents of the buildings. Since the reflecting walls of buildings, in particular of the most recent ones, are composed by a large number of faces and made by materials of a different nature, it was considered allowable to adopt, for each individual building, an average reflection coefficient with respect to the extension of the vertical surfaces of the same. In this way, the operation of association of the material to a single vertical surface is more simple. First of all, from an operational point of view, we proceeded to the definition of a topological relationship for the construction of the vertical walls. This relationship is necessary to transform the polygonal feature in a linear feature, that is representative of the plan view of the i-th wall to which the relative height can be associated. Instead, the attribution of the average coefficient of reflection of the vertical walls to each building was carried out through a their visual analysis, that has been made with the aid of information provided by google-maps, where possible, or through the outcomes of the direct investigations This simplification has been particularly useful for the urban fabric, which could be complex from the morphologic point of view. This one has adopted in order to streamline the input provided to the algorithm and speed up work. Finally, as regards the construction of the index for the control of the factors of urban morphology, we have considered the local volumetric density (I3) and the Thermal dispersion index (I4), in order to automate the procedure in a GIS environment.

3.2 Results and discussion

After that the database has been implemented with the measured values, we have proceeded with the construction of the factor maps representing the block's spatial distribution of the index of control of permeability and vegetation and the index of control of albedo factor (Fig.3,a;b).

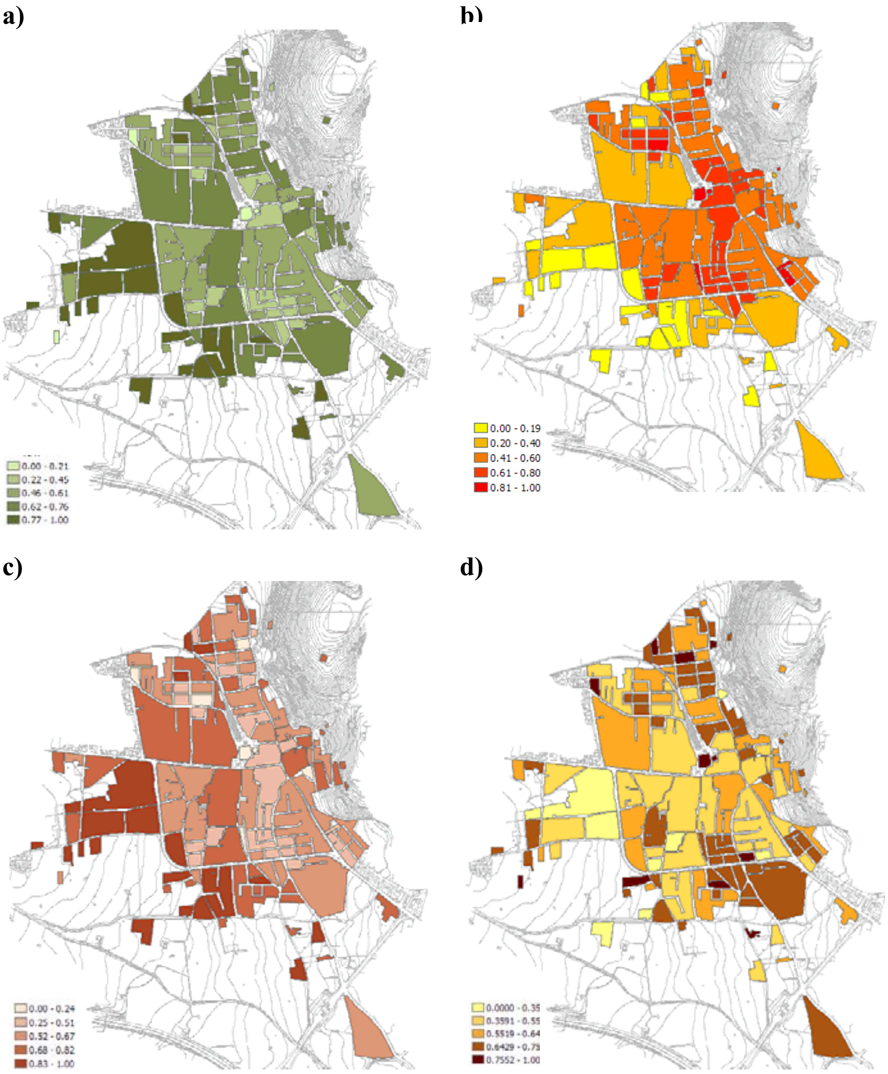

Fig. 3. factor map representative of the spatial distribution of each indicator: I1 (a); I2 (b); I3 (c); I4 (d).

Moreover we have built the factor map of the local volumetric density and the of the index of compactness on buildings ((Fig.3,c;d).

Looking at the category of green spaces, the corresponding factor map records the spatial variability of the components of permeability and vegetation that are related to the variations of the rates of evapotranspiration and surface runoff about the different types of land cover. In particular, the map shows how the settlement fabric is characterized by values of the index totally placed in the middle class of intensity range, presenting however, especially within the mainly dense fabric, blocks characterized by medium to high levels.

Concerning the class built-up areas, that let to investigate the effect of the urban island of heat determined by the urban structure, the factor map is representative of the component of urban materials and shows values of the index, i.e. medium - high, on over all urban fabric, with the exception of the suburban area.

The factor map I3, that is representative of the component of urban morphology, shows a concentration of density of buildings with intensity mostly medium-high, as shown also by the factor map I4, bringing out a substantial correlation between the two values.

It was subsequently built the factor map ISUT, by a linear combination performed with operations *mapalgebra* of factor's map for each indicator.

As described in the methodology, the spatialization and the classification of the obtained values, using the "natural breaks" classification's method identifies a scale of intensity of the phenomenon, for the urban fabric, considered divided into 5 classes according to the literature.

The operation was carried out for both the *base scenario* and the *design scenario*.

Looking at the base scenario, the map highlights the critical points of the settlement fabric investigated, represented by blocks characterized by a ISUT value belonging to medium-low and low classes (Fig.4,c).

The results obtained for the ISUT value in the design scenario, namely for the sectors planned as new areas of settlement development of the MUP, let to obtain the factor map of all areas of the project. This also allows to make judgments about the sustainability of the changes brought by the choices of spatial planning that need to individually reach a programmed level of acceptability, namely a greater ISUT's value than the maximum range present in the intensity scale identified.

Placing, in fact, the focus on the sector C7 (Fig.4,c) shows that the planned transformation, according to the assumptions used, is placed in the upper class of the scale of intensity defined.

Established that can be considered acceptable and, therefore, sustainable, the medium-high and high thresholds,it is clear that the transformation in question exceeds the average level of sustainability of the fabric where it is integrates.

It is, finally, evaluated the impact of all the changes on the level of sustainability of existing tissue, measured by comparing the average value of the ISUT of each block, calculated for the base scenario and the design scenario.

In particular, for the case in question, there is an increase of the percentage of the average ISUT's value and, therefore, it is evident that, basically, the new interventions, although of reduced dimensions, contributes, overall, to improve the energy and environmental quality of the existing settlement fabric to which are added

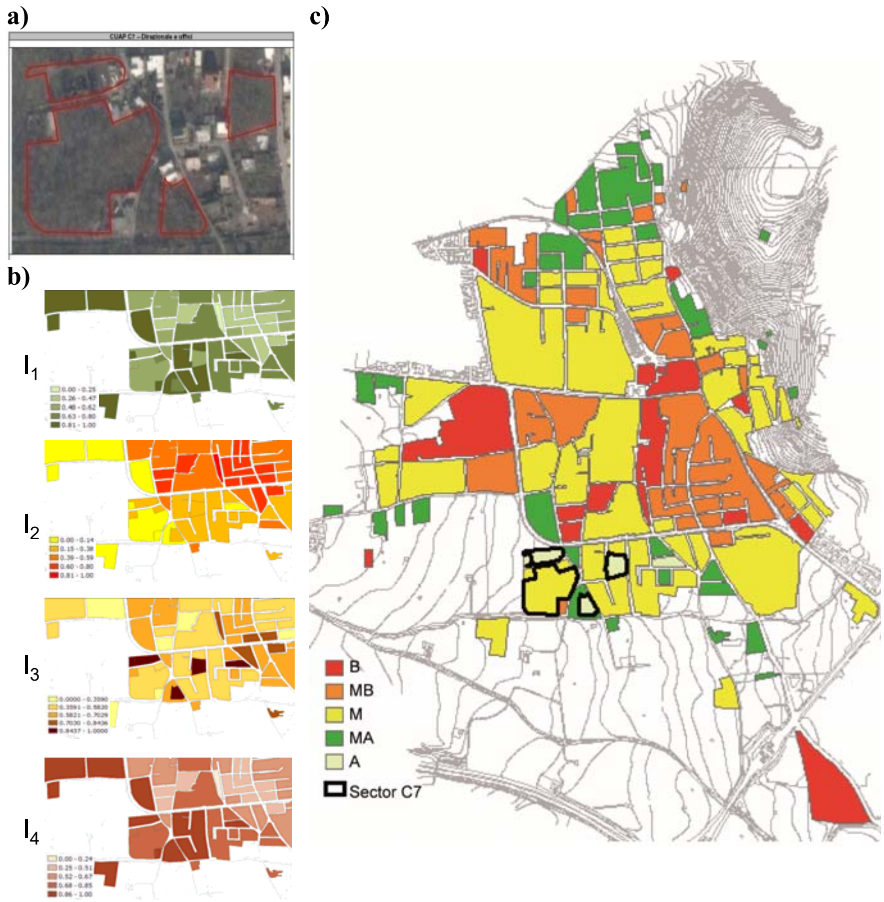

Fig. 4. sector C7 a); Factor map design scenario: I1, I2, I3, I4, b); factor map representative of the spatial distribution ISUT for basic scenario and design scenario c).

The results show how that the index ISUT has the potential to be used for the comparative analysis of the sustainability performance for the production of information of land use, reliable and detailed, at the urban scale.

The spatial scale is an important aspect of assessment in detecting the impacts of urbanization on natural resources and ecosystems.

In fact, the scale of the assessment influences both the identification of the actors of environmental issue and the range of possible actions and policy responses (Weins, 1989; Levin, 1992; Millennium Ecosystem Assessment, 2003).

The set of indicators has been selected considering the characteristics of land use, the sustainability issues, the strategies of environmental planning and the availability of data.

Moreover, the indicators, at the urban scale, are effective tools in monitoring the complex phenomena, increasing transparency and accountability with the provision of widespread access to information, engaging stakeholders, supporting policymaking and allowing comparisons across time/space with other municipalities/regions.

The ISUT is basically a static index of sustainability, since it provides information for a specific moment and allows us to understand the wider impacts of urbanization.

However in the application ISUT has used like a dynamic index, between the base scenario and the design scenario, because, to support appropriate actions of planning, is necessary to understand and explain the relationships between the different factors that change over time.

As regards the aspects evaluation, the ISUT provides a comparative evaluation between these scenarios.

However, sustainability should be judged by some threshold standards on a scale of absolute values, because sustainability is not a relativistic concept (Fischer et al., 2007).

We should note that it is difficult to fix such absolute limits in decision-making, based on ecological and environmental thresholds, although they are essential for assessing the sustainability of the city.

The result is that it is essential to provide an absolute evaluation with a certain standard or thresholds until you can.

4 Conclusion and future developments

The explained methodology shows that appropriate designing criteria helps to enhance global energy and environmental quality of the existing urban frame, namely the object of urban planning.

The ISUT helps to support the processes of land's government, both in the design and testing of new settlements, both for planning projects of ecological and energetic redevelopment of the existing urban fabric.

Specifically, it permits (1) the definition of the benchmark of the current situation, the strengths and weaknesses; (2) the evaluation of the efficiency of the required implementation plans, and (3) the measurement of advancements towards sustainable development.

The future developments of the methodology consist in the sensitivity analysis of the model with reference to the procedures of weighting. The application has been implemented an Equal weighting which uses the measurement of each indicator with the same degree of importance.

With regard to the overcoming of an assessment only based on the comparison between scenarios, we should prepare, gradually, large records of data to be able to locate and consolidate the analysis's values, especially of the partial indexes, such as to make significant results of the individual application.

Is needed a wider trial about the ISUT, necessarily it has to be applied in multiple and different settlements in order to compare the different intensity classes and validate threshold values of reference. This validation requires the definition of standard urban structure, which is ideal reference and that should be extracted using a parametric comparative analysis of the different components that contribute to the formation of the ISUT. In this way we'll be able to identify possible correlations between parameters in play and see which of them influence, in a more sensible way, the value of the ISUT.

By working in this way, we can further refine the judgments of value in terms of energetic and environmental sustainability, both for the existing urban fabric and for the new ones.

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