17th International Conference on Environmental Science and Technology

Athens, Greece, 1 to 4 September 2021

Rapidly growing cities and critical environmental issues: An evaluation model to support policy-making

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Abstract. The use of multi-criteria analysis methods as a decision support tool plays a crucial role in defining spatial policies oriented towards environmental quality enhancement, social and cultural development, and economic feasibility. In order to support sustainable city governance processes, purpose of this research is to define an innovative model for the selection of urban regeneration projects. Innovative elements concern both the sequence of calculation algorithms, based on a rational and repeatable hierarchical scheme, and the selection of criteria and corresponding evaluation indicators, to be referred specifically to the analysis of investments for rapidly growing cities with strong environmental issues.
Keywords: Urban Regeneration; Environmental Decision Making; Multicriteria Analysis.

1. Introduction

Sustainable urbanisation issues need to be supported by governance policies that balance economic growth, environmental integrity, and socio-cultural development. (Parry *et al.*, 2018). The challenge of achieving sustainable urban development is of extreme urgency in developing countries, where rapid and uncontrolled growth of cities is increasingly common.
While on the one hand these dynamics offer opportunities for economic and social development, on the other hand they have multiple negative impacts on the territory (Peponi and Morgado, 2020; Dolores *et al.*, 2020). In fact, unplanned urban sprawl can lead to complex urban problems, from loss of green cover and biodiversity to land use/land cover change and energy inefficiency; from groundwater depletion, to the increase of inadequate housing facilities. It can also cause significant environmental pressures related to traffic congestion, water, and soil contamination, increasing levels of environmental pollution, solid and liquid wastes, insufficient drainage, sewage problems, as well as social hardship related to the slum's formation and the lack of services (Aburas *et al*., 2016; Albino *et al.*, 2017).
In other words, the development of cities, if unplanned, weighs on the sustainability of the ecosystem, making it necessary to carry out urban renewal, understood as a general process of transforming the urban environment.
Therefore, the use of multi-criteria approaches can provide valuable support for sustainable city governance processes (Nesticò and Somma, 2019; Macchiaroli *et al.*, 2019; Calabrò, 2020). In this respect, several sector studies develop assessment systems for urban renewal projects based on multi-criteria schemes.
Aburas *et al.* (2015) argue that the application of innovative techniques is urgently necessary to advance the concept of sustainable growth. This can be done by integrating the Geographic Information System (GIS) and the Analytic Hierarchy Process (AHP). as a multi-criteria analysis/evaluation technique for land suitability analysis for urban growth. Polat *et al.* (2016) propose an approach for the selection of urban renewal projects based on the joint use of AHP and PROMETHEE methods. Again, Bottero *et al.* (2018) propose a multi-methodological approach, combining SWOT Analysis, Stakeholder Analysis and PROMETHEE method for the evaluation of alternative urban renewal strategies.
The aim of this paper is to select criteria and related indicators to guide sustainable investment choices in cities characterised by rapid growth and environmental challenges. This is based both on a study of the literature in the sector and on an analysis of initiatives in urban areas marked by environmental problems, poor infrastructure and inadequate economic development. The aim is to define a rational and traceable hierarchical scheme to support the whole environmental decision-making process.

2. Methods

The Analytic Hierarchy Process (AHP) is among the most widely used techniques to solve Multicriteria Decision-Making problems. The AHP uses a multilevel hierarchical structure of objectives, criteria, sub-criteria and alternatives. This is to provide a ranking of the overall performance of each alternative based on each individual evaluation criterion.
The implementation of the AHP requires 5 fundamental steps.

1. *Setting up the hierarchy*. It is necessary define the hierarchical scheme of the problem by first

establishing the goal to be achieved; therefore identifying criteria useful for the pursuit of the goal. The evaluation criteria can be expressed through sub-criteria down to the level of detail necessary for an exact understanding of the problem. The last level is defined by the alternatives to be evaluated. (Saaty, 1999).

2. *Matrices of comparisons in pairs*. Having known all the information on the decision problem, we construct: (i) the matrices of the pairwise comparisons between the criteria of the same hierarchical level; (ii) the matrices of the pairwise comparisons of the alternatives with respect to each criterion and sub-criterion. Pairwise comparisons are made using the Saaty semantic scale.
It is a scale with scores of 1, 3, 5, 9 which correspond to judgments that express the result of the comparison (Tzeng *et al*., 2011). The matrices A of pairwise comparisons are of the type:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1m} \\ a_{21} & a_{22} & \cdots & a_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nm} \end{bmatrix}$$

Such matrices are:

- positive, that is all the principal minors are positive, where by principal minor we mean the determinant of the square sub-matrix formed by the first n rows and m columns (with $1 \leq m \leq n$);
- reciprocal, being $a_{ij} = 1/a_{ji}$ and therefore the elements on the main diagonal are all unitary ($a_{ii} = 1$). This relationship of reciprocity arises from the need to guarantee the symmetry of judgments of importance;
- constituted by finite elements, since for each criterion C considered we have $a_{ij} \neq \infty$.

3. *Determination of weights*. Estimation of the weights of each criterion and of the scores of each alternative is required. Therefore, it is necessary to normalize the matrices obtained from the previous step. In this way, the vector W is determined by relating each element of the matrices of type A to the sum of the elements placed in the same column and then calculating the arithmetic mean of each of its rows:

$$w_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}$$

$$w_i = \frac{\sum_{i=i}^{n} w_{ij}}{n}$$

4. *Consistency analysis of the judgments*. This step allows you to check if the weights obtained in the previous phase are consistent. This is by estimating the Consistency Ratio (CR), as a function of the weights and number of criteria.

Binary comparisons are sufficiently consistent with each other if:

CR < 5% per n = 3;
CR < 9% per n = 4;
CR < 10% per n > 4.

A CR value above the threshold denotes an inconsistency in the attribution of values to pairs. If so, pairwise comparisons will need to be reviewed (Saaty, 1999).

5. *Principle of hierarchical composition*. The global weights (or priorities) of the actions are calculated by applying the principle of hierarchical composition. Thus, starting from the lowest level of the hierarchy, the products between the local scores obtained for each criterion for each alternative and the weight of the criterion are added up. The total score obtained allows you to determine an order of preference: an action (a plan, a project, a program, etc.) will be all the more preferable the greater its overall weight.

3. Selection of evaluation indicators for projects in rapidly growing cities

The AHP is a useful tool to support decisions regarding urban regeneration projects (Velasquez *et al.*, 2013). Therefore, the goal of this research is to select a panel of criteria and related sustainability indicators on which to set up the hierarchical evaluation scheme. This scheme derives both from the study of sector literature and from the specific analysis of case studies concerning rapidly expanding cities, and consequently, with severe environmental problems, infrastructural deficiencies and inadequate socio-economic development.
The first level criteria are:

- *Environmental criterion* (C_{EN});
- *Social criterion* (C_S);
- *Infrastructural criterion* (C_I);
- *Economic criterion* (C_{EC}).

The environmental criterion can be explained in the following second level sub-criteria:

- *Air pollution* (C_{EN1}), expressed through the "percentage of traffic reduction" indicator, which is linked to a reduction in carbon dioxide emissions into the atmosphere;
- *Water pollution* (C_{EN2}), for which the "capacity of the wastewater treatment system for inhabitant" indicator is considered;
- *Hydraulic regime* (C_{EN3}). This sub-criterion can in turn be broken down into further third level sub-criteria:
- *Permeability* (C_{EN31}), as “ratio between dredged m^3 and city surface”, understood as volumes of material dredged from rivers and lakes. This sub-criterion expresses a greater accumulation capacity of water basins;
- *Floods* (C_{EN32}), measured with the "percentage of embankments restored" indicator, which leads to a reduction in river flooding.

The social criterion can be described through the following second level sub-criteria:

- *Improvment of hygienic-sanitary condictions* (C_{S1}), indicator "percentage of inhabitants who connect to the sewer system and/or the aqueduct" and who therefore enjoy better hygienic conditions;
- *Community benefits* (C_{S2}), rendered through the "percentage of families who improve their quality of life" indicator. This indicator expresses the percentage of families who lose homes and agricultural land following the construction of the works envisaged by the project, but receive subsidies from the state for resettlement and training, thus moving towards a better standard of living.

The infrastructural criterion can be interpreted into the second level sub-criteria:

- *Road accessibility* (C_{I1}), measured with the indicator "ratio between the kilometers of roads restored or built from scratch and the number of families", estimating that on average each family owns a means of transport;
- *Urban green* (C_{I2}), whose indicator is "the ratio between the m2 intended for green areas and equipped areas and the entire city area".

The economic criterion can be interpreted by the second level sub-criteria:

- *Tourist attraction* (C_{EC1}), "percentage of tourism increase" indicator, due to the greater attractiveness of cities as a result of the actions implemented;
- *EIRR* (C_{EC2}), or the "internal economic rate of return".

Among the economic sub-criteria, in addition to the EIRR, tourism is also worth considering, as the urban regeneration programs that have been examined generate significant effects on this sector.

Table 1 summarizes the description of the analysis criteria and the related evaluation indicators. Figure 1 gives the proposed hierarchical scheme.

Table 1. Description of the criteria and evaluation indicators

N.	Criterion	Indicator description
C_{EN1}	Air pollution	% traffic reduction
C_{EN2}	Water pollution	Capacity of the wastewater treatment system for inhabitant
C_{EN31}	Permeability	Ratio between dredged m^3 and city surface
C_{EN32}	Floods	% embankments restored
C_{S1}	Improvement of hygienic sanitary conditions	% inhabitants who connect to the sewer system and/or to the aqueduct
C_{S2}	Community benefits	% families who improve their standard of living
C_{I1}	Road accessibility	Ratio between the kilometers of roads restored or built from scratch and the number of families
C_{I2}	Urban green	Ratio between the m^2 intended for green areas and equipped areas and the entire city area
C_{EC1}	Tourist attraction	% tourism increase
C_{EC2}	EIRR	Economic internal rate of return

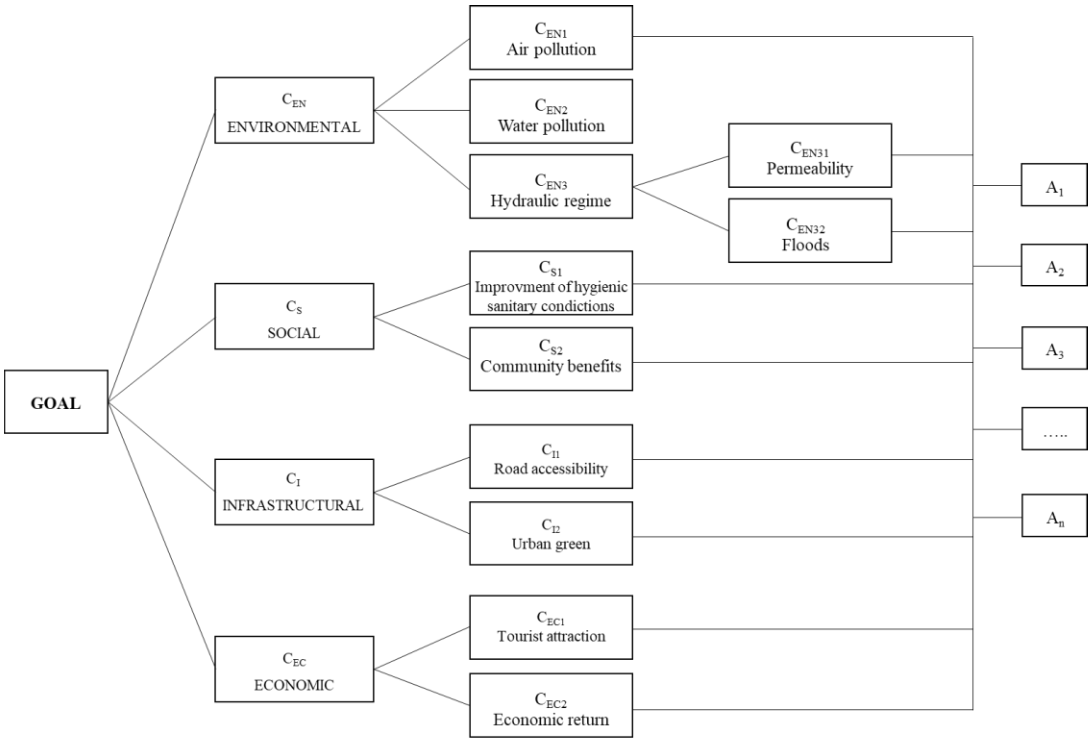

Figure 1. Hierarchical structure

4. Conclusion and future developments

Sustainability can be seen as a paradigm for future thinking in which environmental, social, and economic concerns are balanced in the drive for a better quality of life (Laininen, 2019). Pursuing sustainable development is an even more complex challenge in rapidly urbanising cities. Indeed, unplanned growth in such urban areas can lead to negative impacts on the natural and man-made environment. (Parry *et al.*, 2018). For this reason, it is necessary to direct the decision-making process towards transformational measures of urban environment taking into consideration the interplay between physical, social, environmental, and economic objectives.

This paper formalises a hierarchical multi-criteria scheme useful for selecting urban regeneration projects in territorial contexts marked by rapid growth and strong environmental pressures.

From the analyses conducted, the need emerged to introduce - alongside the environmental, social and economic dimensions - the infrastructural criterion, which takes into account: (i) road infrastructure, through the sub-criterion "road accessibility"; (ii) green infrastructure, which not only increases the resilience of cities but also provides a wide range of ecosystem services (Di Marino *et al*., 2019).

In addition to air and water pollution, the environmental criterion considers the hydraulic regime, which is seldom considered in assessments. The latter criterion is expressed as a function of the greater or lesser storage capacity of reservoirs and the percentage of embankments that intervention initiatives plan to restore. The increase in the number of households gaining access to essential sanitation services and the number of households increasing their standard of living defines the social criterion.

Finally, the economic dimension includes the "economic return" criterion, which evaluates the economic performance of the project, and the "tourist attraction" criterion, which examines the effects of the tourist induced by the project on the territory.

The output of the study is therefore a panel of sustainability indicators able to define a multi-criteria evaluation scheme for better urban planning and suitable decision making. This can lead to greater effectiveness in the allocation processes of public financial resources.

Applications to case studies for testing the model, also revealing criticalities and research perspectives are underway.

(*) *The paper has to be attributed in equal part to the two authors.*

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