Proposal for an Integrated Approach to Support Urban Sustainability: The COSIMA Method Applied to Eco-Districts

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Abstract Cities represent the places with the greatest environmental and energy impacts in the world. Their transformation through a sustainable key would make possible reducing the pressures registered in these areas. According to the Sustainable Development Goals, attention has shifted more and more to the creation of sustainable and safe communities, characterized by low energy-consuming buildings due to smart heating and cooling systems, and sustainable transport solutions based on the use of private electric and hybrid vehicles. Besides the energy and environmental impacts, actions to tackle climate change provide the opportunity to create collateral benefits that can potentially generate economic and social improvement for the whole community. The co-benefits inclusion in the decision analysis is crucial to remove barriers and reveal the real potential of renovation projects at the urban/district scale. Following the guidelines of the European Commission, the tool used when evaluating public projects and policies is the Cost–Benefit Analysis (CBA). One of the main limitations of the CBA method is the estimation of all positive and negative externalities in monetary value that can lead to imprecise assessment. To overcome this obstacle,

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a growing scientific literature on the application of Multi-Criteria Decision Analysis (MCDA) to assess the sustainability of investment at district scale is emerging. In this study, we propose a new assessment framework based on the COmpoSIte Modeling Assessment (COSIMA) to address the multidimensionality that characterizes the redevelopment process of eco-districts considering energy, environmental, economic and social evaluation criteria. The COSIMA method enables considering both the tangible and intangible aspects of the problem and the opinion of the various stakeholders involved in the decision-making process, which are crucial aspects in urban transformations.

Keywords Decision-making · Co-benefit · Urban renovation · SDG 11 · Energy transition

1 Introduction

Nowadays, cities occupy about 2% of the Earth's surface, but they are responsible for 70% of the global primary energy consumption. About 50% of the world's population lives there, and it is estimated that it can reach 75% in 2050. Therefore, given their high concentrations of people, services and consumption, cities play an essential role in the process of energy conversion towards a sustainable society. This process, closely linked at climate change mitigation, represents one of the most significant challenges of the twenty-first century, as recognized on Paris Agreement. Cities are seen as the starting point for achieving the objectives set by the UNFCC in the context of the Sustainable Development Goals (SDGs) (UNFCCC 2015; UNFCCC 2017). In particular, SDG11 aims to create inclusive, safe, resilient, and sustainable cities by stressing the need to take concrete steps to promote a process of transformation towards a green vision of urban areas.

Moreover, in the transition to a more sustainable future, the role of cities is increasingly recognized and evidenced by the spread of the post-carbon cities (PCC) concept, which is also shifting to a smaller scale of intervention through the creation of post-carbon districts (PCD) (Becchio et al. 2016). This constitutes something intermediate between a city and a building, representing the most appropriate scale to test the various transformation strategies of the urban system, making them more manageable, and to contain risks. However, it is important to highlight that district does not correspond to the simple sum of its buildings, but includes the whole of all parties that make up the urban system such as buildings, mobility, public lighting, open spaces, water and waste management.

In this context, the transformation measures must be programmed according to a long-term vision and all their impacts must be assessed, to ensure the achievement of the predefined objectives. The objectives are not limited to respecting the energy and environmental targets of the construction sector. The energy policies can lead to various positive social, environmental, and economic impacts that can bring added value to the choice of alternative strategies. To facilitate the transformation process, the benefits that can be generated by the requalification measures and the various impacts that they can cause for the whole community must be considered (Ürge-Vorsatz et al. 2014; Bisello and Vettorato 2018). Therefore, new support instruments and criteria are needed for considering these impacts, considered fundamental in a complex context such as the urban one, where several stakeholders with different interests are present (Wang et al. 2009).

In this study, we propose a model to assist planners, architects, and engineers in the field of energy and sustainable planning on a district scale in order to control the multi-dimensional problem in this domain. The model is based on an input/output approach. The inputs are made up of energy needs, renewable energy sources, mobility's fuel consumption, water expenditures, costs, and so on. The outputs consist of tangible economic benefits and intangible impacts. The balance of negative and positive impacts is assessed through the COmpoSIte Modeling Assessment (COSIMA) approach proposed by Barfod et al. (2011). In this approach, the Cost–Benefit Analysis (CBA) is extended by adding evaluations of the Multi-Criteria Decision Analysis (MCDA) to economic results through a value function calculated using a weighting procedure. According to MCDA theory, the criteria weighting makes it possible to consider stakeholders' opinion in the decision process, which otherwise would be omitted through a traditional evaluation procedure.

The following section illustrates the eco-district concept. The third section describes the methodological proposal. Results are presented in Sect. 4 and conclusions follow.

2 The Concept of an Eco-District

The examples of eco-districts and sustainable neighborhoods in Europe are quite vast. Concerning sustainable districts, the predominance of examples from Northern or Eastern Europe exists, while examples from Southern Europe are rarely mentioned in the literature. This vision could be supported by the fact that the sustainable neighborhood concept is defined as a Northern European model by the literature (Kyvelou et al. 2012).

The literature gives an extensive range of definitions of the so-called eco-district model. Bottero et al. (2019) and Marique and Reiter (2014) analyzed the characteristics of different real projects in order to develop some empirical insights into the relationships with sustainability in neighborhoods and its related models. In selected cases, energy aspects have certainly been identified as a priority in developing eco-districts. The transition to renewable energy sources (RESs), such as PV systems, heat pumps, or CHP, represents a crucial action to design a sustainable district (Becchio et al. 2018). The adoption of high-performance insulation systems and the development of the first attempts to develop passive houses and nearly zero-energy buildings are both more common (Barthelmes et al. 2016). Other urban sectors involved in the sustainable process of the districts are water and waste management. Various actions and technologies are applied in these sectors with the aims to collect, separate, and reuse them. An extensive range of initiatives occurs on the local scale, such as the reduction of water consumption in buildings and the improvement of municipal waste management.

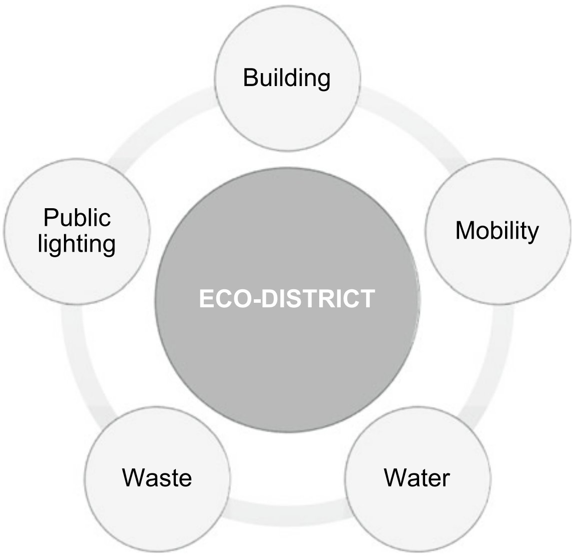
Private and public transports represent another intervention area. Very similar actions were adopted in the various projects analyzed by the authors. The main goal of the measures proposed in this field of application is to discourage the use of private cars by implementing public mobility infrastructures. Besides, the use of private cars is discouraged by the rise of car-free parking in the peripheral areas and by a reduction in the number of parking lots in the center area of the cities. Carpooling and car-sharing initiatives are promoted if the cars are electric or hybrid.

Some projects envisage the energy efficiency of the public lighting system. The technologies implemented do not merely aim at replacing the lighting element with LED lamps. In pilot cases, smart poles provide for the installation of new measures in the field of Information and Communication Technologies (ICT) for the sharing of traffic data or data for monitoring urban air quality (GrowSmarter project 2020).

Some solutions were identified in the urban fabric design of the districts. The most frequently adopted actions covered the development of mixed-use buildings, enabling the combination of various services and facilities with the residential functions. High-density areas are also encouraged to reduce land use and to increase the number of green spaces.

The definition of eco-district covers all the sectors of the entire urban system. In addition to the buildings (B), which become an active part of the energy system, the sectors of water (W), waste management (WM), public and private mobility (M), public lighting (P) come into play (Fig. 1). From this perspective, a combined assessment model for supporting the decision-making process of alternative scenarios

Fig. 1 Eco-district dimensions



of sustainable transformation for a district is needed (Grujić et al. 2014). Starting from the most common approaches used in the field of investment evaluations, an approach that combines the potential of Cost–Benefit Analysis (CBA) and Multi-Criteria Decision Analysis (MCDA) is proposed to include financial and economic aspects, as well as intangible impacts generated by urban redevelopment projects.

3 Methodological Proposal

3.1 Evaluation Framework

The sustainable measures applied at the district and urban levels need innovative methodologies to consider the multi-dimensionality of the decision problem. The evaluation process has to go beyond simple reduction of consumption and investment costs indicators in order to address the full range of impacts involved.

As said before, the main purpose of the model proposed in this work is to support planners, architects, and engineers in the field of energy and sustainable planning at the district scale. The proposed methodological process for the assessment of districts transformation requires a series of steps that enable simultaneously considering the different urban elements that make it up (e.g., buildings, mobility, public lighting, water and waste management) (Fig. 2).

First of all, it is necessary to consider the state of the art (SOA) of each element of the urban system to study the starting point and to identify the retrofit actions to be applied.

With reference to energy consumption of buildings, it is unthinkable to analyze them individually. As shown by Ballarini et al. (2014), an archetype-based approach can help identify the reference buildings (RBs) when working on a large scale representing the heterogeneity of a city's building stock by dividing it into specific classes. Geographic Information System (GIS) could play a crucial role for classifying RBs in an existing real district (Mutani et al. 2016; Delmastro et al. 2016). Each class is based on features (e.g., date of construction and geometrical and thermophysical features) to which energy needs and consumptions, expressed in kWh/m^{2}y and estimated by the modeling of the representative RBs, are linked. In this way, the real buildings in the district are grouped into clusters according to the identified classes. In this way, the real buildings of the neighborhood are grouped into clusters according to the identified classes. First, an energy consumption is associated with each group of RBs, and then the overall consumption of the whole district will be determined.

Regarding waste management, municipal collection plans can provide information to both analyze the current state and define future scenarios.

The mobility sector can be reviewed starting from the local mobility plans that have the task of providing the public administration with the appropriate tools to address, in the logic of anticipation, the new needs of citizens and businesses.

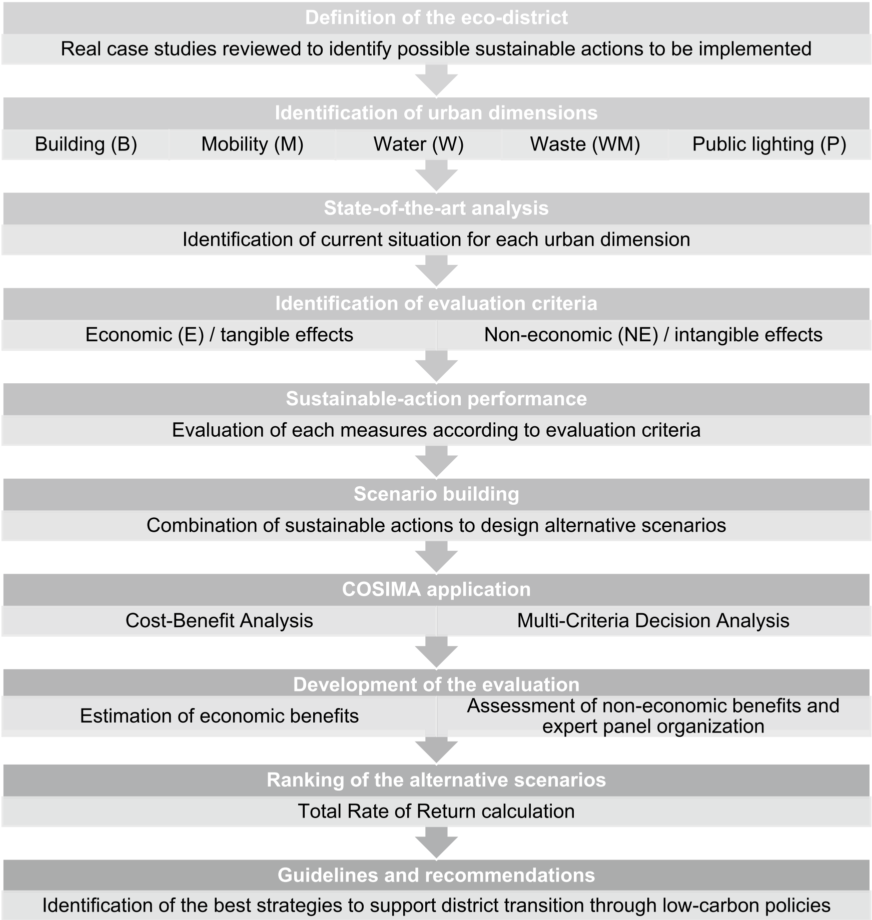


Fig. 2 Flowchart of the proposed method

Once the SOA is defined, it is necessary to plan the retrofit actions for each sector. New measures need to be designed for energy consumption, mobility, waste collection and water treatment. The measures subsequently need to be combined in alternative scenarios to identify guidelines and recommendations for the municipality.

In order to compare the alternative scenarios, the next step is the macroeconomic assessment in which economic and non-economic benefits are considered. Benefits must be identified and quantified for each scenario. To do this an assessment methodology that allows to compare the different scenarios through an aggregated index is necessary. The CompoSIte Modeling Assessment (COSIMA) analysis (Barfod et al. 2011; Barfod and Salling 2015) can be a support tool in this phase. It can be briefly explained as an analysis that combines the CBA (European Commission 2014) and the MCDA (Keeney and Raiffa 1993; Figueira et al. 2005). Indeed, COSIMA measures the performance of each scenario through an index that aggregates the results of both CBA and MCDA, namely the Total Rate of Return (TRR), represented as follows (1):

$$\mathrm{TRR}(A_k) = \frac{TV(A_k)}{C_k} = \frac{1}{C_k} \cdot \left(\sum_{i=1}^{I} (p_i \cdot X_{ik}) + \alpha \cdot \left(\sum_{j=1}^{J} \left(w_j \cdot Y_{jk} \right) \right) \right) \quad (1)$$

where A_k is alternative k, C_k is the total investment costs; p_i is the unit price for the CBA impact i; X_{ik} is the quantity of the CBA variable i; w_j is the weight for the criterion j of MCDA; Y_{jk} is the value score of alternative k under criterion j; and α is an indicator that expresses the trade-off between the CBA and MCDA.

Therefore, COSIMA considers co-benefits expressed in monetary terms (as in the case of CBA) and non-monetary benefits that are defined through both quantitative and qualitative Key Performance Indicators (KPIs).

One of the main potentials of the COSIMA method compared to traditional CBA is the possibility of considering the opinion of various stakeholders in the assessment. Indeed, the decision-makers, as subjects interested in the evaluation of the alternatives and in the choice, can define the degree of importance of the aspects that characterize the project by assigning the weights to the criteria. In order to define the weight w_j of each non-economic criteria j, the Simple Multi-Attribute Rating Technique Extended (SMARTER) procedure could be used (Barron and Barrett 1996). SMARTER derives weights from a simple classification of criteria and is very effective compared to direct weighting. The proposed methodological framework thus set up aims to provide guidelines for future actions in terms of energy and urban sustainability at the district scale, identifying the potential of each measure in the overall performance according to the different actors connected to the process.

4 Results

Since the COSIMA analysis includes non-monetary criteria in addition to monetizable benefits, it is useful to define a list of parameters to be considered in the evaluation starting from a review of the literature on the co-benefits generated by the regeneration process. This phase was useful for defining the evaluation variables to consider all the urban sectors (B, M, P, W, WM) involved in the district-scale transformation processes. The criteria selected from the review analysis are shown in Table 1. The criteria range from environmental aspects to energy, economic, and social ones (Bertolini et al. 2018; Gabrielli et al. 2019; Dell'Anna et al. 2021). Each of them is evaluated using a quantitative or qualitative indicator. The quantitatively

Table 1 Economic and non-economic impacts in redevelopment project at the district scale

Evaluation criteria	Unit	Criteria type		Urban sectors				
		E	NE	B	M	P	W	WM
Energy saving	€/kWh	×		×		×		
CO_2 emission avoided	€/CO_2ton	×		×	×	×		×
PM_{10} emission avoided	€/PM_{10}ton	×		×	×	×		×
Real estate market value increase	€/m^2	×		×			×	
New green jobs	€/new green job	×		×			×	
Fuel costs avoided	€/kg or €/l	×			×			×
Increase in public transport passengers	Passenger/km		×		×			
Reduction of drinking water usage	l/per capita		×				×	
Covering renewable energy sources	%		×	×				
Visual impact	Qualitative scale		×	×	×		×	×
Reliability of technology	Qualitative scale		×	×	×		×	×
People acceptance	Qualitative scale		×	×	×		×	×

assessed impacts will be identified through a unit of measurement, while the qualitative ones will be identified through a level scale that will vary according to the criterion considered.

As shown in Fig. 3, the results of the CBA and MCDA analysis can be examined separately, to identify the performance of different alternative scenarios based on

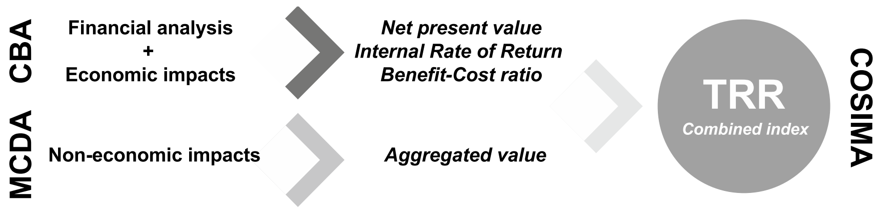


Fig. 3 Interpretation of the results

economic (E) and non-economic (NE) values. Furthermore, by combining the results of the two analyzes according to the COSIMA approach, the complete performance of the scenarios is calculated considering the entire range of impacts through the TRR index. By introducing the results of the MCDA into the TRR calculation, the different points of view of the actors participating in the decision-making process are taken into account. In this way, the COSIMA analysis allows to build a participatory, iterative and transparent decision-making framework by analyzing the different urban sectors affected by the transformation.

5 Conclusions and Future Development

According to the new European standards, the inclusion of co-benefits in the decision-making process has significant importance in the field of defining energy policies on an urban and district scale to better describe the performance of alternative projects and choose the one that maximizes the co-benefits. In this study, a multi-step methodology for the evaluation of alternative retrofit scenarios of a hypothetical district has been proposed. The proposed methodology foresees a preliminary analysis of the urban sectors that characterize an eco-district and subsequently identifies the useful evaluation criteria to highlight their potentiality in the sustainable transition. To evaluate the feasibility in terms of economic and non-economic benefits generated by the redevelopment project, the integration of the COSIMA method in the evaluation framework is suggested. The proposed multi-step approach consists of integrating the purely economic analysis of the costs and benefits with a quantitative and qualitative criteria that considers the non-monetizable impacts. This multi-step approach enables overcoming the difficulties related to the application of the manual-based CBA, that admits the consideration of the only benefits that can be monetized, excluding others that have the same importance for the environmental, economic, and social development of a neighborhood. The co-benefits reviewed in this framework appear to be suitable to represent the complexity of the problem under consideration, and the synthetic index of the Total Rate of Return seems to be useful for informing decision makers on the priorities of alternative retrofit scenarios.

Given the fragmentation of stakeholders within the urban context, this participatory and iterative decision framework may guide the choices in redevelopment and new sustainable measures considering their opinions (Sarnataro et al. 2020; Capolongo et al. 2019; Cerreta et al. 2019). The integrated framework seems to be suitable to respond to the needs of public administrations for a decision support system capable of addressing the issues that come into play at the urban level from a sustainable perspective (Assumma et al. 2019; Napoli et al. 2020). The implementation of the proposed methodology will make it possible to evaluate alternative retrofit scenarios of real world case studies concerning the redevelopment of districts considering different urban sectors (buildings, waste, water, mobility). Subsequently, the results of the evaluation will support the definition of future actions and policies for urban regeneration in a sustainable perspective.

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