Multi-criteria decision support system for urban energy group planning and decision-making activities

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Multi-criteria decision support system for urban energy group planning and decision-making activities

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Abstract

The choice among Urban Energy Planning (UEP) scenarios is broadly based on multi aspects. Hence, the Multi Criteria Analysis (MCA) basing on stakeholders-oriented approach plays a fundamental role in implementing the effective strategies. In this regard, the use of proper supportive tools and methods to address the complex interactions of UEP purposes are needed. This study aims at presenting the final result activities of a national Smart City & Communities project, named "EEB-Zero Energy Buildings in Smart Urban Districts", which is the development of a new Multi-Criteria Spatial Decision Support System (MC-SDSS) for UEP. This tool facilitates the group decisional processes for stakeholders by creating "what-if" questions and visualizing "if-then" scenarios on-the-fly. Specifically, the study focuses on the definition of different energy retrofitting scenarios for the built environment, based on stakeholders' preferences. Accordingly, different decision scenarios have been developed representing a set of retrofitting measures basing on the different hierarchy of preferences of the stakeholders as "stakeholders-oriented" scenario. The tool has been applied and tested to a demonstrator case-study, related to a medium-sized city of the metropolitan area of Turin.

1. Introduction

In recent decades, cities are the main energy consumers in the world contributing to carbon dioxide (CO2) emissions and the leading cause of climate change. Many cities are facing enormous challenges in managing rapid urbanization, which is increasing from the beginning of 20th century (UN-HABITAT, 2009). Over half of the world's population currently are settling in urban areas and expecting to have this number increased to 64-69% by 2050 (IPCC, 2014). Moreover, urban sprawl and the way that cities are growing and operating are among the most visible consequences, along with the increasing of substantial detrimental impacts on the environment and its energy demand (Jaeger et al., 2010). Interestingly, urban areas account for about two-thirds of the world energy (United Nations, 2010).

Cities therefore play a significant role in resolving acute challenges related to climate change and energy transition (IEA, 2016). With the increasing importance of urban areas, among the 17 Sustainable Development Goals (SDGs) identified by UN Agenda 2030, goal 11 is completely dedicated to sustainable cities and communities. Particularly, Goal 11 emphasises the better urban planning and management of cities and human settlements with the aim at making them inclusive, safe, resilient and sustainable (UN General, 2015). In fact, cities are the decisive framework for the development of new strategies and approach in facing climate change and energy transition giving concrete and rapid solutions for more sustainable and eco-friendly human development (UN General, 2015). However, most urban planning systems do not have evaluation and monitoring as an integral part of their operations (UN-HABITAT, 2009). Clear indicators are needed to be integrated within each urban planning systems to monitor and evaluate tactics, strategies and processes. Although a larger scale approach is preferable to a building scale, this concept requires considering an all-new set of sustainability variables, and involving numerous new stakeholders, thus extremely complexifying the decision-making activities. In fact, due to many influences and factors in large-scale plans, their impacts are very difficult to be assessed.

For this reason, new tools and methodology are needed in order to plan of more sustainable cities addressing multiple objectives such as reduction of energy consumption, increase in energy efficiency of systems and adaptation of urban areas to climate change at the same time (Brandon and Lombardi, 2011). According to the current trend, it has now been proven that there is a need to rethink energy efficiency measures at a larger scale, considering the built environment as a tile of a wider area, thus better exploiting the potential synergies between buildings, in economic, social and environmental terms (Torabi Moghadam et al., 2017).

The whole process is indispensable to guarantee a future sustainable urban transformation by investing responsibly in alternative consumption patterns and greener strategies and speeding the decision-making process through participation and intuitive visualization.

According to the given background, this study presents the final result activities of a national Smart City & Communities project, named "EEB-Zero Energy Buildings in Smart Urban Districts", which is the development of a new Multi-Criteria Spatial Decision

Support System (MC-SDSS) for Urban Energy Planning (UEP). This tool facilitates the group decisional processes for stakeholders by creating "what-if" questions and visualizing "if-then" scenarios on-the-fly. Moreover, the study focuses specifically on the definition of different energy retrofitting scenarios for built environment, based on stakeholders' preferences. Accordingly, different decision scenarios have been developed representing a set of retrofitting measures basing on different hierarchy of preferences of the stakeholders: "stakeholders-oriented" scenario. The tool has been applied and tested to a demonstrator case-study, related to a medium-sized city of the metropolitan area of Turin, named Settimo Torinese.

The rest of the paper is organized as follows: details of the proposed framework are illustrated in Section 2. Section 3 presents the results which is the application of the proposed methodology to the case study. This application is used for testing the effectiveness of the proposed framework. Finally, conclusive remarks are discussed in Section 4 and future developments are identified.

2. Methodology

This work assembles research outcomes aiming to illuminate innovative solutions bridging the limitations of the current field of research of UEP, which consists in four main phases of planning according to (Mirakyan and De Guio, 2015): (i) Phase I-Preparation and preliminary analysis; (ii) Phase II-Detailed urban buildings energy modelling; (iii) Phase III-Prioritization and decisional process and (iv) Phase IV-Implementation and monitoring. The methodological framework of this study integrates the first three main phases of UEP presented above, where in each phase several steps, tools and methodologies are involved (Cajot et al. 2017). The specific attention is paid to space heating energy consumption of the residential building stock. The research

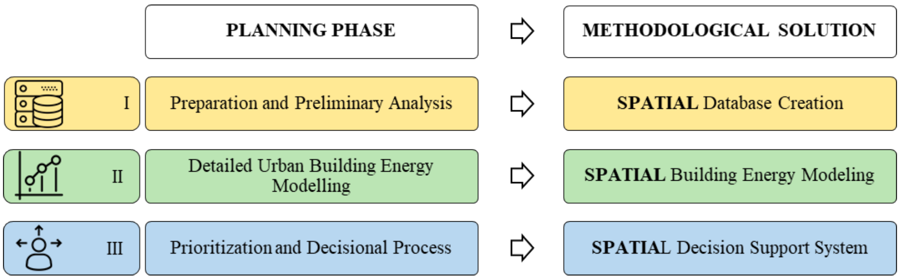

Figure 1 Summary of methodological framework solution for each phase of planning through this study.

The integration of this technical know-how leads to urban energy map evaluating economic, environmental, social and technical indicators resulting from the evaluation of energy saving scenarios. This provides a supportive tool for the urban actors in the group decision making planning processes. Moreover, it allows several stakeholders having different conflicting interests to gather and discuss the issues of several urban saving scenarios (Torabi Moghadam et al., 2019). A new MC-SDSS is an interactive plug-in of ArcGIS 10.3 (www.arcgis.com) environment in order to help dynamically analyze the energy retrofitting scenarios based on the stakeholders' preferences over an urban scale. To this end, in Figure 2 a schematic flowchart of the integrated methodological approach is shown. The methodological approach of this study is presented in a very detailed way in (Torabi Moghadam and Lombardi, 2019).

(i) **Phase I-Spatial database creation**: the study started from collecting the quantitative data and information which led to characterize the building stock and to create a supportive geo-database. This phase is the supportive basis of all next phases (II and III). The GIS database can be continuously updated joining more geo-referenced and non-georeferenced (they need to be geocoded) data into the framework. All the collected data have been then overlapped and integrated into each building polygon in GIS platform. Into this end, the 2D-GIS-database has been created including the several factors, which may effect of the building energy issues. The use of GIS was crucial at the urban scale due to its powerful spatial visualization features and its multiple layers representation.

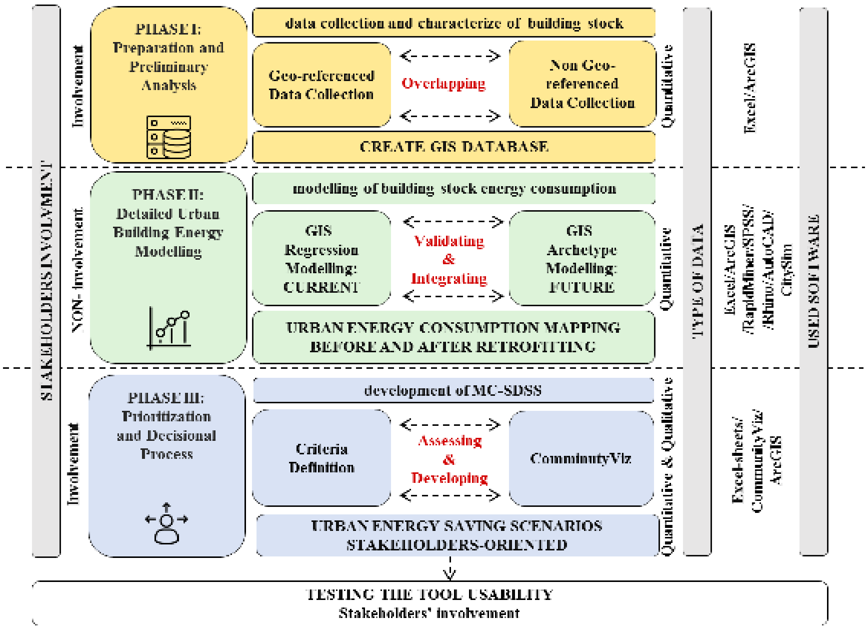

Figure 2 A schematic overview of the methodological approach, elaborated from (Torabi Moghadam and Lombardi, 2019).

(ii) **Phase II-Spatial building energy modelling**: the main goal of this phase was to assess the building stock space heating energy consumption at the current and future city status. The modelling approach is based on the integration of statistical analysis with 2D-GIS (for the current status) and the engineering analysis with 3D-city model (for the future status) (Torabi Moghadam et al., 2018); (Torabi Moghadam et al., 2019); (Mastrucci et al., 2013). In fact, the methodology framework combines both the statistical and engineering approaches to obtain a more robust prediction of the urban energy consumption (Nouvel et al., 2015). The framework is performed in order to assess and to design urban energy saving scenarios. A spatial distribution of urban building energy consumption both in 2D and 3D visualization provides Spatial Decision Support System (SDSS) tool in order to identify the hot-spots zone to make the better decisions and to avoid unnecessary investments.

(iii) **Phase III-Prioritization and decisional process**: the main goal of this phase was first to identify the most relevant evaluation criteria, both qualitative and quantitative through an organizing a workshop involving stakeholders. The definition of evaluation criteria side-by-side the real local stakeholders led to have reliable results that grantee the robustness of planning process. In this study, the "Playing Cards" method is chosen to select the most relevant criteria (Simos, 1990); (Lombardi et al., 2017). Consequently, all the selected evaluation criteria have been assessed and analysed to be implemented in a new MC-SDSS tool. The new MC-SDSS is modelled and coded using an existing interactive plug-in in the GIS environment , called CommunityViz (Kwartler and Bernard, 2001). Since this tool is interactive can provide dynamic feedbacks on changing the assumptions and viewing the influences of changes on the future scenarios in real-time. Furthermore, it engages stakeholders in participative and group decision-making processes through its visualization features in real-time. Finally, a workshop is organized on to test the usability of the tool and to understand its weaknesses and strengths from the stakeholders' point of view.

3. Results

This section demonstrates the tool interface and how it is able to make different dynamic scenarios. All the results and outputs are integrated and assembled to create a new MC-SDSS tool, which came from the introduced phases in Figure 2. The MC-SDSS is an interactive plug-in in GIS environment, which has been adapted from CommunityViz. CommunityViz is an ArcView modular GIS-based decision support system (http://www.communityviz.com) consisting of two main components: (i) Scenario 360 to map and analyse, and (ii) Scenario 3D to visualize (Kwartler and Bernard, 2001).

This dynamic process aids meaningfully in sharing information with the urban actors in a very simple visualization manner providing maps, alerts and charts for such a complex problem as UEP (Wang et al., 2009). Figure 3 shows the interface of Scenario 360 modelled for the specific case study of medium-sized Italian city, Settimo Torinese. Particularly, the tool consists in building dynamic attributes, which are changeable based upon: dynamic data, assumptions (sliders) and indicators.

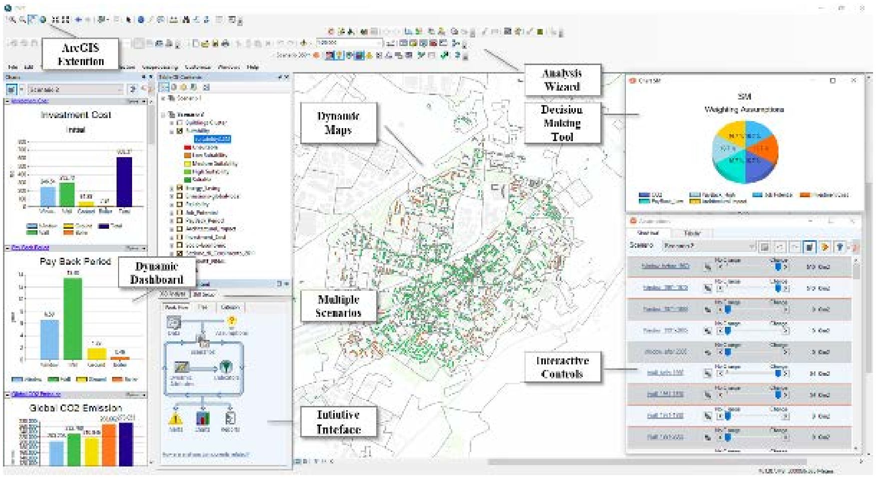

Figure 3 CommunityViz Interface; the case study of Settimo Torinese, source (Torabi Moghadam and Lombardi, 2019)

Moving the sliders bars, the stakeholders can define different dynamic scenarios and visualize the impact of their preferred assumptions. The impact of different scenarios is consequently visible through different charts, maps and indicators. Moreover, the tool provides the ability of comparison among different scenarios and indicators.

Figure 4 shows an example of one of the scenarios defined by stakeholders, so-called "stakeholder-oriented" scenario. In this specific scenario, the stakeholders replaced the glazing ratio windows of older buildings and they isolated the walls and floors of building age 1961-1990; while, they preferred to do not renovate any intervention in terms of energy system. This decision was made because they wanted to see the impact of the envelope system refurbishment that leads to significantly reduce the energy consumption. In this phase of work, the aim of defining different scenarios is not to find the "best" performance scenarios, but it is to test the usability of the tool experimenting it.

As a result, stakeholders can visualize all the criteria related to the following indicators at the urban level both for each retrofit measure and for the total value considering all the measures: (i) total energy consumption (GWh); (ii) energy saving reduction (%); (iii) initial investment costs (M€); (iv) investment cost (€/m2), (v) PBP (year), (vi) CO^2 emissions (tonnes); (vii) CO^2 emissions (tonnes/GWh), (viii) local emissions NO_X (tonnes) (ix) local emissions PM_{10} (kg); (x) job potential (man-day), (xii) architectural impact (rank), and (xiii) reliability of the retrofitting measure (rank).

4. Conclusions

This study integrates different energetical, economical, societal, technical and environmental performances of building retrofitting interventions. The research boundaries are specifically focused on an existing building stock in European context. The relative data and information of the building stock is first collected and geolocated in order to model the energy consumption patterns at the current and future status of the city. The geospatial database was used as the object of multi-criteria analysis assessments. Finally, an interactive MC-SDSS was created to support the decision makers in defining energy saving scenarios in real-time. Within the use of this GIS extension, public administrative users, such as urban energy planners, policymakers and built environment stakeholders can plan, design and manage sustainable cities. This plug-in provides the stakeholders with the ability to visualize interactively and explore a range of possible futures saving scenarios. This methodological approach provides a significant innovative progress in the research field, that is developing an interactive plug-in tool for UEP in the GIS environment.

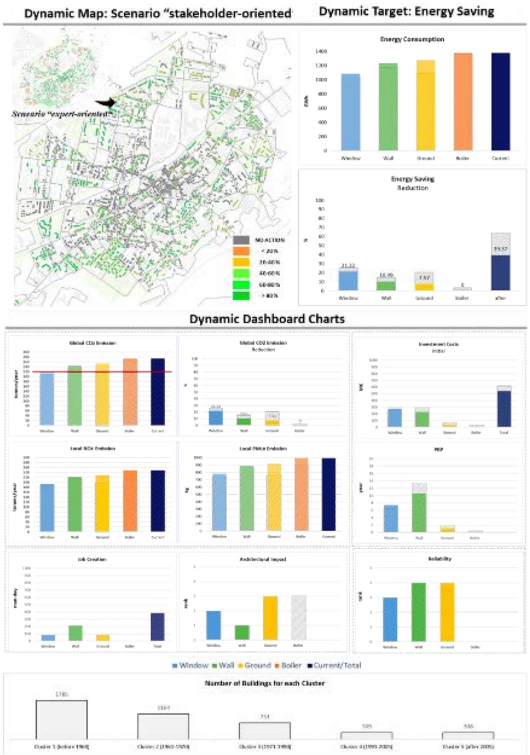

Figure 4 an example of one of the scenarios defined by stakeholders, so-called scenario 2 "stakeholder-oriented".

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Conflict of Interest Conflicts of Interest

The authors declare no conflicts of interest.

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