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An Integrated Participative Spatial Decision Support System for Smart Energy Urban Scenarios: A Financial and Economic Approach

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Abstract: The decision-making process regarding heating supply system options in a district perspective is extremely challenging. This paper aims to present a new method to support urban energy decisions in real-time processes, which was developed in the context of a European project (DIMMER (District Information Modeling and Management for Energy Reduction, 2013–2016)). The method is composed of three parts: (i) a new web-based spatial decision support system (SDSS), called "Dashboard"; (ii) an ad hoc energy-attribute analysis (EAA) tool to be integrated into Dashboard; and (iii) a multi-criteria decision analysis (MCDA). In contrast to other SDSSs, one of the main strengths of Dashboard is the ability to acquire, store, and manage both geo-referenced and non-geo-referenced data, and perform real-time analyses of spatial problems taking into account a wide range of information. In this sense, Dashboard can formally visualize and assess a potentially infinite number of attributes and information, as it is able to read and process very large web databases. This characteristic makes Dashboard a very effective tool that can be used in real-time during focus groups or workshops to understand how the criterion trade-offs evolve when one, or several, decision parameters change. The paper describes the main procedure of the new method and testing of Dashboard test on a district in Turin (Italy).

Keywords: multi-criteria decision analyses (MCDA); DIMMER project; spatial decision support systems (SDSS); cost analysis

1. Introduction

Decision-making regarding heating supply system options in an urban perspective is extremely challenging. Nowadays, choosing an energy improvement at a district level implies considering six main issues [1]: technical (technologies features, spatial boundaries); economical (investment and management costs); environmental (reduction of the CO_2 emissions, NO_x emissions, energy requirements); regulatory (compliance with local standards, and national and international regulations); social (directly related to the citizens' behaviours;, and political (connected to the strategic vision for city development). If the first four aspects can be assessed and quantified with more or less coded procedures [2], the last two open the discussion to consideration of broader and more arduous issues, such as sustainable development and the climate change. The difficulties in handling these subjects are several. First, they represent major ideological battlefields, with a series of political strategies to reduce the dimension of the threat [3] (i.e., climate change is a marginal phenomenon, not worthy of preoccupation; science and technology can solve the problem; leave the solution to the market with higher taxation of the polluters, etc.; pressure on personal responsibility instead of large systemic measures). Second, the large spatial and temporal dimensions of the problem, where cause and effect are spread over time and space, make every prediction and appraisal extremely difficult [4]. Third, although all countries can influence global climate change, not all parts of the world will suffer equally if such change occurs. This distributional difference makes it more difficult to achieve international cooperation and coordination to solve the problem. Finally, directly related to the last point, there is an absence of an existing institutional framework of government able to foster adequate laws to address the problem [4].

In this peculiar context, the choice of the proper heating system for a district and the refurbishment of the buildings mainly constitute an environmental choice, where the reduction of local and global emissions is often an opposing decision. Consequently, such a choice takes on political value, where decision-makers (DMs), citizens, and technicians are called upon to decide whether to reduce the impact of regional choices or larger scale ones. Traditionally, the method used when approaching this type of decision has been a cost-benefit analysis, but it is becoming very arduous because "proffering a discount rate for valuing costs and benefits that will be realised or avoided only centuries in the future and under completely uncertain societal conditions is heroic, foolish, or a mixture of both" [4]. Recent approaches propose to combine financial evaluations, such as discounted cash flow (DCF) analyses [5], cost/benefit analyses (CBA) [6], return on investment (ROI), and energy budget costs [7], with multi-criteria decision analyses (MCDA), able to consider quantitative and qualitative aspects [8–10]. The first allows consideration of the influence of economic and financial investments on the actual property values [5], taking into account the quality of life minimizing the environmental impacts [6]. The MCDA allows for development of an integrated sustainability evaluation, while considering the short-term and long-term effects, conflicting interests and perspectives, and evolving biophysical and socio-economic systems [8].

However, there is another specific feature of the problem that is rarely considered: the territorial dimension. Despite the current availability of many different visualisation tools (systems devoted to support complex decision-making processes in spatial problems) [11], few spatial decision support systems (SDSSs) have been developed in this realm to date [12].

The paper aims to present a new method to support urban energy decisions in real-time processes. The method represents an integrated participative SDSS and it is composed of three parts: (i) a new web-based SDSS, called "Dashboard"; (ii) an ad hoc energy-attribute analysis (EAA) tool to be integrated into Dashboard; and (iii) a MCDA. The method proposed has been developed in the context of the European project DIMMER (District Information Modeling and Management for Energy Reduction, 2013–2016), with the aim of supporting energy decision-making processes at a district scale of intervention. DIMMER aimed to integrate building information modelling (BIM) and district-level three-dimensional (3D) models with real-time data from sensors, and user feedback, to analyse and correlate buildings utilization and provide real-time feedback about energy-related behaviours.

In order to test and validate the new integrated participative method, both public and private buildings in urban districts were considered in two different cities: Turin (Italy) and Manchester (United Kingdom) [13]. The present research reports the first results obtained from the Turin district, while the results for the Manchester district are currently under development.

The paper is organised as follows: Section 2 provides an overview of the SDSS tool developed, with particular reference to the EAA and the MCDA applied; Section 3 illustrates the application to the DIMMER case study, while Section 4 concludes the paper by providing some reflections about the future development of the work.

2. The Spatial Decision Support System (SDSS) Tool

Dashboard, developed in the context of the European DIMMER project, can be considered as a SDSS—a system devoted to support complex decision-making processes in spatial problems [11]. Spatial planning usually involves multiple stakeholders bringing different levels of knowledge according to their experiences and backgrounds. In this sense, the stakeholders need to be supported through enhanced access to information in order to make sensible decisions [14]. In general, the SDSS helps in supporting evaluation and decision-making processes by being able to integrate different subsystems and databases [15], as well as identifying particular zones in the territory according to visual maps [16].

In recent years, many SDSSs have been developed according to different scopes [12,17]. However, to date few have been developed to support energy urban planning decisions [14].

For this reason, one of the main tasks of the DIMMER project was to develop a flexible SDSS tool, which was able to visually support the stakeholders in performing efficient energy decision-making processes.

Thanks to the visual interface, Dashboard (Figure 1) enables dynamically interactive sessions in real-time allowing the exchange of information between the stakeholders and tools, supporting all decision phases of the process [18]. Dashboard has been developed with the technical support of the Information System Consortium of the Piedmont region (CSI—Italy) and it is mainly based on the software Quantum GIS (QGIS) (software version 2.8, GNU General Public License, free available at www.qgis.org) [19] and the virtual globe CESIUM [20] systems.

Figure 1. The Dashboard interface.

In contrast to other SDSSs, one of the main strengths of Dashboard is the ability to acquire, store, and manage both geo-referenced and non-geo-referenced data, and perform real-time analyses of spatial problems taking into account a wide range of information. In this sense, Dashboard can formally visualize and assess a potentially infinite number of attributes and information, as it is able to read and process very large web databases. This characteristic makes Dashboard a perfect tool that can be used in real-time during focus groups or workshops to understand how the criterion trade-offs evolve when one or several decision parameters change [11]. However, visualizing and managing too much information can be counterproductive for the decision-making process, running the risk of confusing the stakeholders and affecting the final decision. It is, therefore, fundamental to carefully choose only the most useful information to properly address the decision. In this sense, Dashboard needs to be optimized in advance for the particular problem, according to the decision-making process that is going to be faced.

In detail, Dashboard implements an assessment framework based on an EAA developed ad hoc according to the requests coming from the DIMMER project and partners. The EAA is focused on the potential refurbishment solutions for building envelope and heating systems [21] (see Section 2.1). Furthermore, Dashboard takes a step further with respect to the visualization of data in order to support MCDA [22].

According to the literature [23], the SDSS can support evaluations and decision-making processes on urban scales about the complexity of the related strategies scenarios, while integrating different subsystems and databases. Interestingly, the GIS can support the decision-making processes related to the definition of energy urban scenarios by identifying critical zones with the use of colored maps [16]. In parallel, the MCDA have proven to be powerful methodologies, able to consider different aspects of complex situations and provide priority rankings, both in terms of alternative scenarios and qualitative/quantitative decision criteria [22].

In fact, during the DIMMER project, Dashboard proved to be a powerful visualization tool. It allowed the stakeholders to express their preferences with respect to decision criteria and/or alternative scenarios using GIS-based procedures, increasing trust in the results. Moreover, the GIS maps can become "visual indexes" offering solutions to the planners to change and optimize the conditions according to their preferences [10,24].

2.1. The Energy-Attribute Analysis (EAA)

The EAA presented here constitutes a sub-section of Dashboard and is directly integrated into the tool. The aim of the EAA is to provide long-term numerical information capable of supporting the stakeholders' decisions according to "what if . . . " scenarios. During the focus groups, the stakeholders can interact in real-time with Dashboard, making interactive energy choices on the territory while visualizing future hypothetical scenarios on the GIS maps. Moreover, they can visualize the changes in a table in terms of attributes, thanks to the EAA. For example, the EAA is able to assess the global installation costs if the stakeholders decide to install the district heating (DH) in all buildings in the considered area, as well as the reduction in terms of pollutant emissions related to this choice.

In terms of details, the EAA takes into account different financial, economic, and environmental attributes related both to the refurbishment/heating supply system options and to the pollutant emissions. This analysis considers the existing buildings because the DIMMER project is focused on energy improvement of the existing stock rather than on new buildings. It has to be mentioned that in Italy only 5% of residential buildings were built in the twenty-first century and, more generally, the European Union estimates that at least two-thirds of existing buildings will still be in place in 2050 [7].

The starting point for designing the EAA was the fact that the European Directive 2010/31/EU of 19 May 2010 [25] obliges the member states to adapt heating systems to the new standards, referring to individual controls and consumption meters. However, Italian legislation delays the application of the aforementioned European Directive. The Italian Legislative Decree, in fact, was issued in August 2016 according to [26]. This delay in transposing the European standards could be explained by two main issues: the costs of installation of the new technologies and a refusal by the population to change their main habits. This is particularly true when talking about multi-family buildings and flat complexes. Historically, the annual heating cost of those buildings was simply divided by taking into account the dimensions of the flats without considering the actual heating consumption of each flat. On the contrary, switching to individual controls and consumption meters, as imposed by the European Directive 2010/31/EU, needs more precise control of the heating consumption, where the annual heating costs are divided according to the real heating consumption. This causes a sort of mistrust among the inhabitants and the politicians, both needing to be convinced and supported in adapting the flats according to the new regulation.

Accordingly, in order to properly assess the problem, we first analyzed the relevant international literature to consider a wide range of sensible attributes in the energy field [27,28]. However, due to the specific requests coming from the DIMMER partners, an empirical analysis of the real estate market in Turin was essential.

Starting from these assumptions, we developed a series of 10 simple algorithms capable of assess sensible attributes over a long time period as supported by the literature, empirical analyses of the territory, and information coming from IREN, which is the main energy operator in Italy and one of the DIMMER partners. The algorithms we developed are able to assess the following attributes at the district scale: (i) the annual fuel consumption of four consumption modes (air heat pump with photovoltaic panels -PV + ASHP-, DH, and condensing boilers); (ii) the global installation costs; (iii) the annual money savings; (iv) the annual CO_2 emissions; (v) the simply payback period (SPBP); (vi) the operation and maintenance costs (O and M); and (vii) and the refurbishment costs.

In this regard, the refurbishment costs must be mentioned. Assessment of them has been arduous and involved the coded costs coming from the official Pricelist of the Piedmont Region [29], together with the costs collected directly from the real estate market [30].

According to this approach, the EAA implemented in Dashboard is focused on different refurbishment interventions of the existing buildings' envelope and heating systems, namely: (i) refurbishment of roof and wall insulation; and (ii) replacement of windows. In contrast to suggestions coming from the literature [28], it was not possible to consider all the available refurbishment technologies due to normative and/or territorial constraints. For example, the installation of ground source heat pumps cannot be pursued in the urban area under examination. It is important to note that the refurbishment costs constitute the most important attribute to be assessed since it affects the other attributes, such as fuel consumption, annual money savings, annual CO_2 emissions, and the SPBP and the annual O and M.

According to [31], for each of the aforementioned refurbishment interventions, the developed EAA assesses different attributes starting from the database developed by [32] within the DIMMER project. It contains real consumption data, the Pricelist of the Region, and empirical analysis on the territory in Turin.

The investment costs have been calculated starting from the parametric coded costs coming from the Pricelist of the Region [29], which is mediated with the installation costs collected on the real estate market in Turin. The parametric investment costs considered in the EAA take into account the design costs, the safety regulations which must be met, the paperwork for the municipality, the scaffolding costs, the costs of materials, and the installation costs.

As an example, Equation (1) has been used to assess the annual fuel consumption of the DH:

$$(F)C_{DH} = 0.1037(Q) \tag{1}$$

in which $(F)C_{DH}$ = annual fuel cost for the *DH* (€), (Q) = heating energy needed (KWh), and 0.1037 = annual fuel price per KWh provided by IREN for the year 2016.

The annual fuel consumption of the DH affects not a single building at a time, but a district. Therefore, the support of IREN has been fundamental in order to properly collect the required costs.

Differently, the annual fuel consumption for the air heat pump and the condensing boilers was assessed starting from monitoring of real heating consumption data collecting during the year 2016 in 200 buildings located in the district under examination [31]. The heating consumption was multiplied by the fuel price, taking into account the different fuel sources and the local fuel market for the year of reference. Following the same approach, it was possible to calculate the annual O and M cost of the heat generators.

Moreover, the developed EAA is also able to assess environmental attributes at different scales, such as the net energy consumption of the heating systems and the global CO_2 emissions. In order to properly consider those two factors, we used the National Emission Factors as reported in [33].

The data assessed by the EAA have been implemented in Dashboard, constituting a tool section available for logged users as buildings administrators, energy planners, and policy-makers. Thanks to the coupling of the EAA and Dashboard, it is possible to develop and compare different energy scenarios at the district level. In this sense, Dashboard compares the performances of the existing buildings with the performances of different refurbished scenarios based on the data assessed through the EAA.

2.2. The Multi-Ccriteria Decision Analyses (MCDA)

In general, the MCDA are valuable and increasingly widely used approaches to help the DMs make decisions in a structured and intuitive way for human minds [22]. Despite the diversity of

MCDA, the basic ingredients are very simple: a finite or infinite set of actions (alternatives, solutions, and options), some decision criteria, and at least one DM. Over the years the MCDA acquired increased popularity in urban planning decisions, since they are able to take into account qualitative and quantitative aspects, such as environmental, social, and economic aspects. Those issues are fundamental when talking about urban planning, where the objectives, alternatives, and criteria are often competing [34].

Among the available MCDA methods, a very important role is played by the measured attractiveness using a categorical based evaluation technique (MACBETH) [35,36]. The MACBETH method is a MCDA, which requires qualitative judgments by the stakeholders in order to quantify the relative attractiveness of an action or a criterion. MACBETH is able to construct a quantitative values model based on the qualitative judgments expressed by reducing the "cognitive discomfort" [37] of the stakeholders when they are asked to express their attractiveness according to a numerical scale [38].

According to the theory, the MACBETH methodology can be divided into three main application phases: model structuring, model evaluation, and results analysis.

Model structuring: the alternatives to be evaluated (called "options"), as well as the values of concern (called "criteria or nodes"), need to be identified. Once identified, they need to be organized in a graph (called a "value tree") which provides a structured overview of the problem under consideration.

Model evaluation: starting from the "value tree", a series of pairwise comparisons are presented to the stakeholders with the aim of identifying the relative attractiveness of the alternative options and/or criteria according to a qualitative scale. The semantic categories used to fill in the pairwise comparisons are: Extreme, Very strong, Strong, Moderate, Weak, Very Weak, No (no differences between the elements).

Results analysis: during this phase, the MACBETH method is able to provide a ranking of the alternative options, as well as of the criteria under examination. In this sense, the alternative options and the criteria are ranked from most attractive to least attractive.

The choice to apply the MACBETH method is due to a number of reasons. First, MACBETH is a simple and understandable methodology, even for those who are not experts in the decision-making process. Second, its technical parameters have a clear and easily explicable substantive interpretation allowing the processing of difficult problems, by relative importance of criteria, in a precise way. Third, the results that MACBETH is expected to produce are lists of *k*-best actions expressed in numerical values to be analyzed further by the people involved. Finally, the M-MACBETH software [39] and the interaction protocol are compatible with the method of reasoning of the test group and with the meaning of useful results.

3. Application to the DIMMER Case Study

The new integrated participative SDSS (namely Dashboard implemented with the EAA in combination with MACBETH) has been tested during the DIMMER project to manage a decision-making process regarding the energy transition of an urban district called "Crocetta" in Turin (Italy). The main objectives of the aforementioned decision-making process were: (i) to discuss the most important decision criteria to be considered in view of an energy change for the district, in line with the temporal and spatial dimensions of the problem; and (ii) to discuss alternative energy hypotheses for the district in a perspective of reducing energy consumption and CO_2 emissions.

The decision-making process has been structured into subsequent phases. After an internal test, a first focus group took place in Turin in December 2015, while a final focus group took place in May 2016. The two focus groups were organized with the participation of stakeholders with actual interests in the local territorial context, including: representatives of the builders' associations, developers, designers, representative of administration offices, and academic experts (energy and economic evaluations). The present paper provides the results from the second focus group.

3.1. Description of the Case Study

The "Crocetta" district is characterized by continuous curtain blocks mainly constructed during the1960s and shaped as large lots with fenced yards. One of the interesting features of this area is the presence of both public and private buildings, which allows studies in order to optimize opportunities on energy saving due to building usage by people at home, at school, and at home during the day.

For the assessment at stake and according to the DIMMER project suggestions, we considered 200 representative buildings in the "Crocetta" district characterized by some lack in terms of energy performance. In order to embrace a wide range of possibilities, the chosen buildings differ in terms of solar orientation, dimensions, technology, construction materials, and use. The heterogeneous characteristics of the buildings, together with the use of real data collected on the territory, allowed consideration of different energy situations permitting a complete analysis during the focus groups. Figure 2 represents the visual GIS interface of Dashboard in which the 200 buildings considered for the analysis are highlighted.

Figure 2. The 200 buildings considered in the Crocetta district geo-referenced on Dashboard.

3.1.1. Setting the Dashboard

The first important step needed to properly conduct the decision-making process with the stakeholders was been the setting up of Dashboard. During the internal test we decided which attributes and information, among those available, were needed for the process under examination. We then integrated them into Dashboard. This is a fundamental step since it allows easy interaction with Dashboard for both the experts and the stakeholders involved. The integrated data had different characteristics. First, we provided geo-referenced data from the CESIUM database [20], namely the physical characteristics of the district, in order to properly geo-reference the buildings considered. Second, we provided information relating to each of the 200 buildings, such as their dimensions in square meters [34], the current heating systems installed, and the current CO_2 and NO_x emissions of the heating systems. Finally, we integrated the EAA sub-section containing the data and information at the district level previously assessed by it: the annual fuel consumption of four consumption modes (air heat pump with photovoltaic panels -PV + ASHP-, DH, and condensing boilers), the global installation costs, the annual money savings, the annual CO_2 emissions, the resulting SPBP, the annual O and M, and the refurbishment costs.

All the integrated data were needed to conduct the decision-making process since they allowed us to classify the buildings according to the heating primary energy source and the nominal efficiency of the boiler. This classification permitted a deep real-time analysis of the energy district scenario based on sensible parameters, even if simulated.

3.1.2. Development of the Alternative Scenarios

After having set up Dashboard, we developed three alternative scenarios (Table 1) based on the relevant literature review on district energy scenarios [28] and the data assessed by the EAA. We considered the possible energy demand reduction achieved by the installation of high-performance windows and exterior insulation and finishing system (EIFS).

In order to develop the alternative scenarios according to the DIMMER project requests, we made the following assumption: in the next 15 years all buildings not currently connected to the DH system, or without a condensing boiler, will have to retrain the heat generation plant [26]. Moreover, considering the technical and economic feasibility, and according to [26], we assumed that the buildings currently connected to the DH would not change their heating system. In fact, the DH connection can be considered a lock-in condition which requires a very large investment cost if it is to be dismantled. The alternative scenarios have been implemented directly in Dashboard in order to stimulate and support the discussion with the stakeholders. In fact, many scholars affirm that the use of SDSS can help the stakeholders in "getting on the same page" [40] and having a collective insight [41] about the issues involved.

Table 1. The alternative scenarios and the decision criteria considered.

Alternative Scenarios			Decision Criteria				
			Investment Costs	**Simple Payback Period (SPBP)**	**Reduction of the CO_2 Emissions**	**Reduction of the Energy Requirement**	**Resilience of the Energy System**
1	Increase of DH	It provides the 87% DH and the 13% condensing boilers; 10% of the building will be refurbished with EIFS.	€8,700,000	30 years	30%	10%	Low
2	Conservative	It provides the 65% DH and the 35% condensing boilers; 20% of the building will be refurbished with EIFS.	€12,600,000	20 years	25%	17%	Medium
3	Extreme	It provides 52% DH and 23% condensing boilers or pellets; 25% heat pumps and photovoltaic panels, while 50% of the building will be refurbished with EIFS.	€30,400,000	10 years	55%	50%	Medium/High

The alternative scenarios considered represent different hypotheses of energy transition, thus stimulating the comparison of different views of the future according to [42]. In particular, Scenario 1 (increase of DH) can be defined as a top-down centralized energy transition (CENT) strategy, which is pursued by the general government without properly considering the needs of the inhabitants of the districts. In this sense, the CENT is usually interesting for the municipal authorities since they can have better central control in terms of plant safety and pollutant emissions [42]. However, it can present some critical issues mainly related to the lock-in system [43], the risk of energy monopoly, and the poor resilience of the plants. It is important to stress that Scenario 1 presents the minimum investment costs because it takes into account the costs incurred by the inhabitants of the district while avoiding the costs related to the heating grid and stations.

Scenario 2 (conservative) is a so-called "business as usual" scenario. In this sense the current heating systems, as well as the buildings components, are refurbished due to obsolescence and are without normative or economic impositions.

Scenario 3 (extreme) reflects a bottom-up societal energy transition (SET) strategy in which the market choices are applied at the district/buildings scale of analysis. In this sense it is able to consider the economic long-term perspective, paying particular attention to needs of the district's inhabitants. This scenario presents the highest investment costs for the inhabitants, but it can be balanced thanks to the low SPBP.

It is important to underline that the alternative scenarios proposed here are extreme simplifications of possible energy development perspectives and their intent is to be both revealing and provocative.

Table 1 shows the decision criteria, as well as the performance of each alternative scenario calculated with the support of the EAA. In fact, a coherent set of decision criteria needed to be identified to properly describe and assess the three alternative scenarios. According to the literature review [44], two economic aspects have been considered as decision criteria: the "investment costs", understood as all the investment costs related to refurbishment of the buildings and the new energy resources, and the "SPBP", which reflects the performance measure used to evaluate the efficiency of an investment or to compare the efficiency of a number of different investments [45]. In terms of environmental aspects, we decided to consider the criterion "reduction of the CO_2 emissions" as suggested by [9]. Moreover, "reduction of the energy requirement" considers the improvement of the energy performance related to the buildings' planned interventions [8], while "resilience of the energy system" represents the ability of the scenario to soak up economic and physical shocks of the energy system. The last two decision criteria can be considered as technical aspects of the problem and they reflect direct concerns coming from the DIMMER project requests.

3.1.3. The DIMMER Focus Group

After defining the alternative scenarios and the decision criteria, we were better situated to start the focus group supported by Dashboard, having all the required information to structure the decision problem according to the MACBETH method. Thanks to the M-MACBETH software (software version 1.1, BANA Consulting, Lisbon, Portugal) [39], a series of questions related to the decision criteria and the alternative scenarios have been posed to the stakeholders involved. The questions were of the type:

> *(1/a) Looking at the decision criteria under examination, rank them from most preferred to least preferred.*
>
> *(1/b) According to the rank so far provided, to what extent do you prefer one criterion to another?*
>
> *Example: I strongly prefer the criterion "Investment costs" to the criterion "PBP" and I weakly prefer "PBP" to the criterion "Resilience of the energy system".*

All the stakeholders' opinions were collected during the focus group and then aggregated. Many methods have been proposed to approach this aggregation n the literature. The most widespread ones are the geometric average (GA) and the arithmetic average (AA). The literature [46,47] indicates that the GA is the "evolution" of the AA, but this does not mean that one is better than the other. It depends on the context of application. For example, if asked to find the class average of students' test scores, an AA would be used because each test score is an independent event. On the contrary, if one were asked to calculate the annual investment return on your savings, one would use the GA because the numbers are not independent of each other (i.e., if you lose money one year, you have that much less capital to generate returns during the following years, and vice versa) [48]. Moreover, since the GA gives a null global score even if only one criterion is null, there is a risk of flattening the values so much that differences between the elements of the decision in the final stage are not captured properly.

After applying both methods, and since the answers given in the surveys are independent events, we decided to apply the AA on the basis of majority weighting. This means that preference was given to the node that had the highest number of votes, and then among these weights the AA was determined. This last approach can be defined as a "majority" method, because it is somehow similar to a political election, where the winner is the party that obtains the highest number of votes (for an in-depth analysis see [49], while for application in an urban/territorial realm see [50,51]).

The resulting final ranking of the decision criteria and alternative scenarios are reported in Table 2.

Table 2. Final ranking of the decision criteria and alternative scenarios.

Criteria Ranking	Criteria Scores	Scenario Ranking	Scenario Scores
Investments costs	30	Scenario 3	47.50
PBP	27	Scenario 2	29.03
Reduction of the energy requirement	23	Scenario 1	23.46
Reduction of the CO_2 emissions	18	-	-
Resilience of the energy system	2	-	-

According to the answers provided during the focus group, the best alternative scenario for the "Crocetta" district turned out to be Scenario 3 (47.50%) from the perspective of pursuing a bottom-up SET strategy giving importance to the autonomy of choice of the district's inhabitants. In fact, the stakeholders involved, even if they gave the highest importance to the investments costs, also judged as fundamental the PBP and the reduction of the energy requirement. In this sense, Scenario 3 is able to maximize those aspects in the long-term, by considering the preferences of the private investors and business operators. Indeed, those stakeholders paid particular attention to the investment costs and the requested PBP. At the same time, the environmental preferences advocated by the public stakeholders are met since the CO_2 emissions are minimized thanks to the use of clean fuels, such as pellets and biomass. In this sense, Scenario 3 seems to be able to reconcile aspects that are usually antithetical.

On the contrary, the stakeholders considered Scenario 2 as less interesting (29.03%) with respect to Scenario 3. In fact Scenario 2 is financially affordable, requiring lower investment costs, but it does not meet the requested performances in terms of the reduction of CO_2 emissions and energy requirements. Finally, Scenario 1 turned out to be the least preferred one (23.46%) despite the optimal performances in terms of investment costs. In fact, the stakeholders involved considered the CENT strategy as not interesting mainly due to the low possibility of reducing the CO_2 emissions and to the energy requirement. Moreover, the lock-in system and the possible energy monopoly that could occur in Scenario 1 are not in line with the idea of profitability and development advocated by private investors.

The use of Dashboard has been fundamental in order to come to the aforementioned results since it allowed the stakeholders access to all the information required for discussion. The possibility of "seeing" the data on a geo-referenced visual interface enhanced the awareness on the territory under examination, as well as on the energy and economic performance of the 200 buildings considered (Figure 3). This can be claimed because of two elements: (1) the ethnographic observations of the workshops; and (2) the participants' affirmations, interviewed after the workshops.

Figure 3. Visualization of the annual O and M costs for each considered building.

Figures 3 and 4 represent an example of real-time interaction with the use of Dashboard. In fact, the stakeholders involved in the decision-making processes had the possibility of choosing the buildings to be transformed, the consumption mode to be installed, and the building refurbishment. According to their choices, the EAA integrated into Dashboard provided the results in real-time in terms of CO_2 emissions, annual O and M costs, annual fuel consumption, and refurbishment costs.

It is important to stress that Dashboard provides both visual (Figure 3) and numerical (Figure 4) results. In the example, Figure 3 reports the visual results obtained in terms of annual O and M costs according to the choices of the stakeholders: green buildings have the lowest annual O and M costs, while the red ones have the highest costs. Moreover, according to the same choices, Figure 4 provides the numerical results for each building. Finally, three graphs immediately highlight the differences from the current situation to the assessed one, according to the expected energy consumption and CO_2 emissions.

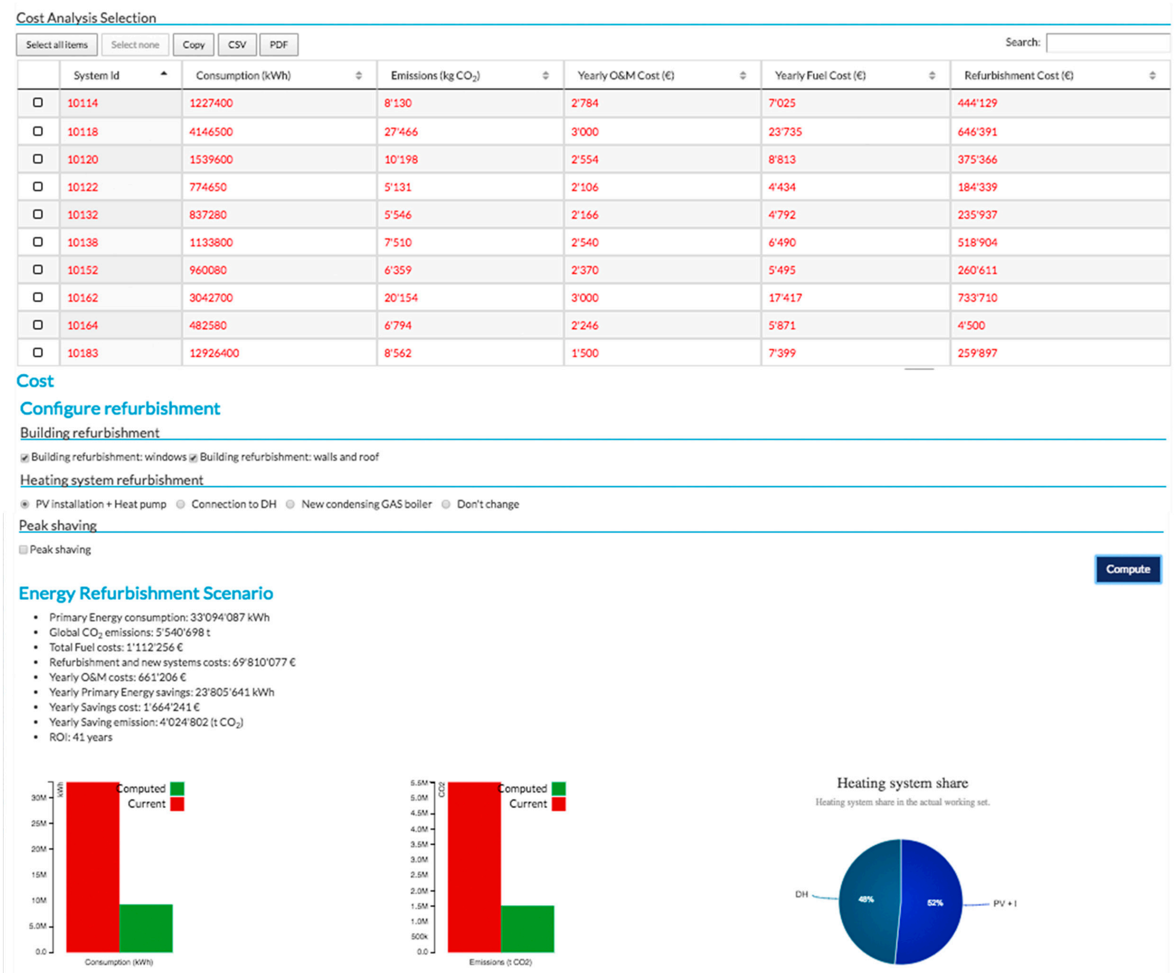

Figure 4. The EAA tool integrated into Dashboard.

4. Conclusions

This paper proposes a new integrated participative SDSS finalized to sustain urban energy decisions in real-time processes. It illustrates how Dashboard can compare the performances of the existing buildings with the performances of different refurbished scenarios, based on the data assessed through the EAA. Mention must be made of the fact that, unlike many visualization software approaches which require very long processing times, Dashboard can instantly edit the maps, allowing it to be used in extremely effective terms during focus groups and meetings.

Moreover, the MCDA is conceived as a further element supporting Dashboard, in terms of use in real decision-making processes with particular reference to the EAA. The objective of the MCDA application reported in the previous sections was to simulate decision-making processes involving real stakeholders, in order to test if Dashboard is able to support the definition of district policies. In this sense, the MCDA turned out to be very useful as it integrated complex and specific assessment criteria and it objectified the elements of discussion.

Dashboard allows for a comparison of the performances of different buildings, as well as the development of different energy scenarios in real-time during the focus group. In fact, selecting a group of buildings and choosing among different refurbishments, it is possible to visualize the performance of the new hypothesis of scenarios according to the available data on Dashboard.

In this sense, Dashboard proved to be particularly useful for both private and public investors. On the one hand, the private investors can visualize different possible choices in terms of energy refurbishment, in order to be better informed when choosing the best possible alternative scenario, considering their private economic interests. On the other hand, Dashboard is useful for the public authorities that need to gain awareness of territories over which they do not have legal rights, but that are affected by their decisions.

The next step of the research is to transform Dashboard into a real multi-criteria spatial decision support system (MC-SDSS). Currently the MCDA and the SDSS are separate applications performed through different software applications [21,22].

In conclusion, the experiment conducted shows the possible contribution of visualization and evaluation tools to switch from a building perspective to a district one. As the energy demand reduction is a key objective for both public and private operators, to allow further progress on enabling investment decisions for future projects, these results could be applied in other districts of the city and to other cities.

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