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TOWARDS SUSTAINABLE SMART URBAN DISTRICT: A MACBETH APPROACH

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Abstract

Lowering energy intensity and environmental impacts of buildings is becoming a priority in environmental policies in Europe, considering that cities produce about 80% of all GHG (Greenhouse gas) emissions and consume 75% of energy globally. The big challenge is to find a way to improve the energy performances of existing housing stock representing the majority of the urban fabrics in European cities.

In order to tackle these issues, the paper illustrates a multicriteria assessment model in the frame of a European project named DIMMER (District Information Modelling and Management for Energy Reduction), which aims to promote energy efficient behaviours integrating BIM (Building Information Modelling) and district level 3D models with real-time data from sensors and user feedback. The assessment model is here applied in order to rank energy development scenarios of a district in Turin (Italy) taking into account both different power generation plants.

The methodology here applied is a multi-criteria method named MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique), an Additive Value Model method requiring a non-numerical approach to build a quantitative value model.

The decision process is divided into four phases: 1) analysis of the decision problem and structuring the model using data obtained trough the DIMMER database; 2) validation and improvement of the model via a focus group with experts in the field; 3) weighting of the elements at stake; 4) analysis for the results.

The point of view of the end users is adopted in order to implement the assessment and find the most probable development scenario.

1_Introduction

Many solutions are today designed in a "green" context including reducing greenhouse gas emissions, saving energy, optimising a process with regard to sustainability criteria, enabling participation and/or reducing poverty (Hilty et al., 2013).

ICT (Information and Communication Technologies) are recognised as being key players against those tasks particularly when dealing with energy: pervasive sensors and actuators can efficiently control the energy chain (Smart Thermal/Electricity Grid). On the other side, advances on 3D modelling, visualisation and interaction technologies enable user profiling and real-time feedback to promote energy efficient behaviours.

To unlock the intrinsic potentialities of those technologies, the Politecnico di Torino started to coordinate a European project called DIMMER (District Information Modelling and Management for Energy Reduction). The DIMMER project (www.dimmer.polito.it) consists of a software system that is made of a collection of components centred on the DIMMER middleware.

The DIMMER technology is intended to be used by energy managers and public authorities to monitor district energy data as well as simulate and implement energy management policies at district level. The main focus of

the DIMMER project are: 1) modelling the integration of Building Information Models (BIM) with real-time data and their extension at the district level (DIM-District Information Modelling); 2) developing middleware able to integrate different data sources: Building Information Model (BIM), System Information Model (SIM) and Geographic Information System (GIS); 3) optimising the exchange of information on ICT new platform and DBs improving interoperability; 4) visualise real-time energy related information in the building and district environment, using virtual and augmented reality.
In order to validate the DIMMER innovative system, both existing and historical public and private buildings included in urban districts are considered in two different cities: Turin (Italy) and Manchester (The United Kingdom).
Despite the undeniable and intrinsic potentialities of the ICT, it is difficult to determine whether the benefit of smart solutions will materialise under real-word conditions particularly when dealing with smart solutions for energy saving affecting users behaviour.
In order to deal with this aspect of the problem, the authors of this study decided to apply a Multicriteria Decision Analysis (MCDA) (Figueira et al., 2005; Roy and Slowinsky, 2013) to identify and analyse the most important criteria to be considered in view of a energy change in the district's scenario and, at the same time, identify the best future energy scenario for the district in exam.
The research reported in this paper is ongoing and illustrates the first assessment exercise based on a focus group about the pilot district "Crocetta" in the city of Turin. The DIST department of the Politecnico di Torino hypothesized different energy development scenarios finalised to a reduction of the energy consumption and CO_2 emissions for the district starting from the data provided by the DIMMER software.
The paper shows a simulation of a decision process involving real stakeholders. It was structured through MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique) in order to discuss the decision criteria and rank the alternative energy scenarios. The reasons why the authors choose this method rather than others is explained in the next section.
After the introduction, the paper is organized as follows: section 2 is dedicated to the MACBETH methodology; section 3 briefly explain the case study and the application of the methodology; section 4 contains the conclusions and the further developments.

2_Methodological background of the evaluation method

The method used in this study is the MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique). This is a MCDA developed in the early 1990's by Bana e Costa C.A. and Vansnick J.C. (Bana e Costa and Vansnick, 1997a, 1997b, 1999; Bana e Costa et al., 2010). The MACBETH approach is based on the Additive Value Model (Figueira et al., 2005) and requires only qualitative judgements about differences of value to help an individual or a group quantify the relative attractiveness of the options.
Starting from the qualitative judgements requested to the decision maker (DM), the MACBETH method allows the construction of quantitative values model (Bana e Costa and Oliveira, 2002; Bana e Costa and Chargas, 2004;

Bana e Costa et al., 2004). This supports an interactive learning process about the problem and the elaboration of recommendations (Von Winterfeldt and Edwards, 1986) reducing the “cognitive discomfort” (Fasolo and Bana e Costa, 2009) that could arise in the DM when he/she is asked to express his/her preferences in a numerical scale.

There are theoretical researches and practical applications of the MACBETH method in different fields as, for example: evaluation of bids and measures of European structural programs (Bana e Costa et al., 2002a, 2002b); territorial planning projects and real estate market (Bana e Costa and Correa, 2000; Bana e Costa et al., 2008; Frenette et al., 2009; Méndez at al., 2014); evaluation of material suppliers (Oliveira and Lourenco, 2002); education (Cuadrado and Gutiérrez Fernández, 2013); waste management (Dhouib, 2014); energy consumption (Ertay T. et al., 2013; Marques and Neves-Silva, 2015).

The choice to apply the MACBETH method (Bana e Costa and Vansnick, 1997a, 1997b; Bana e Costa and Oliveira, 2002), among the different multicriteria techniques available, is due to a number of reasons. First the MACBETH is a simple and understandable methodology even by those who are not experts in the decision process. Second, its technical parameters have a clear and easily explicable substantive interpretation allowing the processing of difficult problem of relative importance of criteria in a precise way. Third, the results that the MACBETH is expected to bring are lists of k-best actions expressed in numerical values to be analysed further by the people involved. Final, the M-MACBETH software involved (www.m-macbeth.com) and the interaction protocol are compatible with the way of reasoning of the inquired people and with their meaning of useful results.

The MACBETH methodology can be divided into three main application phases: model structuring, model evaluating and analysing the results.

Model Structuring: During the structuring phase, the options to be evaluated and their performances as well as the values of concern need to be identified. The MACBETH approach permits the evaluation of different options or alternatives (understood as any potential course of actions) against multiple criteria. Any option is, in and itself, a mean to achieve an end. Good decision-making therefore, requires deep thought about what one wants to achieve through which the values that are of concern with the specific decision context will emerge. Some of these may be broadly defined while others may be more specific (Bana e Costa, 2001). The specific values of the evaluation are called “criteria nodes” while the broadly defined values, or the elements for which only vague information are available, are called “non-criteria nodes”. Structuring these values in the form of a tree, generally referred to as a “value tree”, offers an organised visual overview of the various concerns at hand (Bana e Costa and Vansnick, 1997a).

Model evaluating: After structured the model, MACBETH involves a series of pairwise comparisons, where the DM is asked to specify the difference of attractiveness between all of the alternatives with respect to the criteria. In order to fill in the pairwise comparison matrices, the following semantic categories are used: Extreme, Very strong, Strong, Moderate, Weak, Very Weak, No (no differences between the elements).

The options can be scored in two ways: directly comparing the options two at a time (direct comparison) or indirectly through the use of a value function built by comparing pre-defined performance levels rather than the options themselves (indirect comparison). In this second scoring mode a value function will be used to convert any option's performance on the criterion into a numerical score (Figueira et al., 2005).
As the judgements are entered into the matrices, the MACBETH uses an algorithm based on linear programming (Bana e Costa et al., 2010), in order to verify their consistency. After that, the performance of each option on each criterion is transformed into a value score that measures the relative attractiveness of the options on that criterion (Sanchez-Lopez et al., 2012).

Analysing the results: Once the model has been structured and filled in, the MACBETH method provides very clear results in the form of ranking allowing identify the attractiveness of the problem's criteria and alternatives. During this phase, extensive analyses can be performed to provide a deep understanding of the problem, contributing to attain a requisite evaluation model: the sensitivity analysis can be performed in order to visualize the extend to which the model's recommendation would change as a result of the change made to the weight of the criteria; the robustness analysis can be performed in order to explore the extend to which conclusions can be drawn given varying amount of imprecise or uncertain information (Bana e Costa et al., 2004).

3_The case study

The "Crocetta" district in Turin (Italy) is characterised by continuous curtain blocks shaped by large lots with fenced yard. The area has both public and private buildings that allow studies in order to optimise opportunities on energy saving due to the building usage by people. DIMMER collects data about the thermal energy consumption for all the pilot buildings connected to district-heating (around 60) with non-invasive sensors, but some buildings have been selected as representative of the district to test the ICT invasive sensors provided by the DIMMER project and be thoroughly investigate, are 4 schools, 1 university residence, 1 office and 4 private buildings. These buildings are different for orientation, dimension, use, technology, materials and construction period. Moreover, the possibility to have into the district schools for each levels of education, will allow researchers to test the communication system that will be developed with the DIMMER project with different students in order to improve their awareness on energy saving using targeted solutions and technologies.
Since the DIMMER project and the research presented are on going, some information about the problem in exam still need to be collected. For this, during this first focus group, we considered not the entire district but 20 buildings for a total amount of 502 show flats. 10 buildings are currently connected to the district-heating while 10 buildings are not connected. The assessment focus group presented in this paper is the first of a series of focus group that will be organised under the DIMMER project during the year 2016 with the aim of finding the best energy scenario for the district "Crocetta", and developing more general considerations about the heating systems at district level.

The objectives of the assessment were therefore many: 1) to talk over about the considered assessment criteria; 2) to identify any additional criteria that should be considered in order to implement the model for future focus group; 3) to identify the best energy scenario for the district in exam; 4) to test the MACBETH method for the management of a decision process in the energy planning field.

3.1_Model structuring

Three alternative scenarios were developed by the researchers of the DIST Department of the Politecnico di Torino (Table 1) basing on literature review about district energy scenarios comparison (Paiho et al., 2013, 2014) and according to the DIMMER project's feedbacks.

The alternative scenarios have been compared through the use of the MACBETH method starting from the following assumption: in an hypothetical horizon of 15 years, due to obsolesce and/or to emission regulation on heating boilers, all the buildings not currently connected to the district-heating or without a condensing boiler will have to retrain the heat generation plant (Piedmont Regional law 13/2007).

It's important to underline that the three alternative scenarios proposed are simplifications of possible energy development perspectives. The alternative scenarios' intent is to be revealing and provocative in order to stimulate the discussion during the focus group.

Energy scenario		Description
1	Max District Heating	Huge development of the district-heating. The 80% of the buildings will be connected while the remaining 20% of the buildings will install a condensing boiler.
2	Min District heating	The district-heating is locked to the current situation. 50% of the buildings will remain connected to the district-heating while the remaining 50% of the buildings will install a condensing boiler (cheapest alternative).
3	Heating and pellet	The district-heating is locked to the current situation. Some users that are connected to the district-heating will change the boilers choosing a condensing or pellet boiler. The users not currently connected to the district-heating will install a condensing boiler or pellet boiler (depending on their annual consumption).

Table 1. Alternative energy scenarios.

In order to structure the model according to the MACBETH methodology, 4 criteria nodes were identified among the information presented in Table 2: **Average investment costs**, **Average maintenance and heating costs** (together considered), **Reduction of the CO_2 emissions** and **Resilience of the energy system**.

Data analysed was provided by DIMMER platform. The data refers to buildings as block of apartments heated by a centralized heating system (generally situated in the basement). Some of the centralized systems are connected to the district-heating network, while others have fuel boilers. Building thermal energy consumption, building heated volume and heating station thermal power are available in the DIMMER database. Costs related to new installation, fuel and maintenance were calculated with the linear regression mode based on data provided by heating System Company based in

DATA	Description	Measure	Current	Scenario 1	Scenario 2	Scenario 3
N° of flats	Number of flats that retain the original heating plant	Number	-	**225**	**225**	**317**
Average investment cost per year and one flat	Investment costs needed to modify the previous heat generating plant	Euro	-	**€ 722**	**€ 1.249**	**€ 2.420**
Average heating cost per year and one flat	Cost related to the generation of thermal energy	Euro	-	**€ 531,39**	**€ 441,22**	**€ 402,32**
Average maintenance cost per year and one flat	Cost related to the maintenance of the heat generation plant	Euro	€ 99,40	**€ 76,41**	**€ 79.81**	**€ 90,54**
Reduction of the CO_2 emissions	Reduction of the pollutant emissions	Percentage	-	**2%**	**6%**	**21%**
Resilience of the energy system	Ability of soak up economy and physical shocks of the energy system	Ordinal scale	-	**Low**	**Medium/ Low**	**Medium**
Percentages of fuel use for each scenario						
District-heating	Percentage of building connected to the district-heating	Percentage	49%	**71%**	**49%**	**27%**
Natural Gas	Percentage of buildings using natural gas as fuel	Percentage	46%	**29%**	**51%**	**50%**
Diesel	Percentage of the buildings using diesel as fuel	Percentage	5%	**0**	**0**	**0**
Pellets	Percentage of the buildings using pellet as fuel	Percentage	0	**0**	**0**	**23%**

Table 2. Scenarios information.

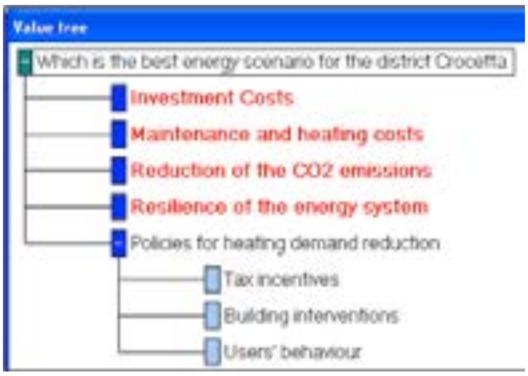


Figure 1. Value tree of the MACBETH model.

Turin. Specifically installation cost was calculated on a basis of 40 thermal station refurbished in the years 2013-2015. Emission data were calculated based on standard data provided by Piedmont Region (46-11968). The criteria nodes and the scenarios were discussed during the focus group. The DMs involved had different backgrounds. They were: 2 representatives of the Turin Builders' Association, 1 real estate developer, 1 designer, 1 representatives of the CSI Piedmont (Consortium for the information system), 1 representative of the Piedmont Region, 1 representative of the metropolitan city of Turin, 1 designer of energy plants and 1 academic expert in energy.

The value tree of the MACBETH model is presented in Figure 1.

Moreover, as a consequence of the focus group discussion, three *non-criteria nodes* related to the policies for heating demand reduction (i.e. tax incentives, buildings interventions and users' behaviour) were added to the value tree, in order to considered them as *criteria nodes* in future assessments.

3.2_Model evaluating

After structuring the model, a free discussion among the stakeholders was finalised in setting up a ranking of assessment criteria in order to identify the most important criterion to be considered in the energy transformation at stake.

All the stakeholders' opinions were collected during the focus group and then aggregated following the "majority method": we gave the preference to the criterion that had the highest number of judgements and we determined then a mathematical mean in order to find the differences of attractiveness (Lami et al., 2014; Lami, 2014) (Figure 2).

Weighting (Which is the best energy scenario for the district Crocetta)

	[MAINT and HEAT COSTS]	[INVEST COSTS]	[CO2 RED]	[ENERGY RESIL]	[all lower]	Current scale
[MAINT and HEAT COSTS]	no	weak	strong	v. strong	positive	41
[INVEST COSTS]		no	moderate	strong	positive	33
[CO2 RED]			no	weak	positive	19
[ENERGY RESIL]				no	positive	7
[all lower]					no	0

Consistent judgements

extreme, v. strong, strong, moderate, weak, very weak, no

Figure 2. Criteria judgements.

As it is showed in Figure 2, the most important assessment criterion turned out to be **Average maintenance and heating costs** (41%) followed by **Investment costs** (33%), **Reduction of the CO_2 emissions** (19%) and **Resilience of the energy system** (7%). Therefore, following the reasoning of the stakeholders, the economic aspects of the problem are the most important for the end users facing this energy change while the resilience of the energy system is not fundamental for the decision process because there is currently not a big differences of resilience capacity among the three scenarios. This result reflects a big actual problem about a society change toward energy behaviours less pollutant. All the participants of the focus group working in the energy sector underlined that the economic aspect is still overwhelming compared to the environmental issues.

Going deeper in the MACBETH model, the stakeholders were asked to answer to the pairwise comparisons related to each single assessment criterion. In order to clarify the process, we report two pairwise comparison matrices: the Maintenance and heating costs judgements (direct comparison - Figure 3) and the Reduction of CO_2 emissions judgements (indirect comparison - Figure 4).

Maintenance and heating costs

	SCEN3	SCEN2	SCEN1	Current scale
SCEN3	no	weak	strong	100.00
SCEN2		no	strong	66.67
SCEN1			no	0.00

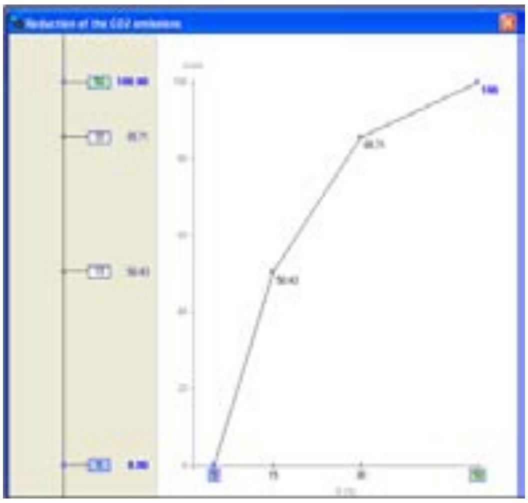
Consistent judgements

extreme, v. strong, strong, moderate, weak, very weak, no

Figure 3. Maintenance and heating costs judgements.

According to scenarios' information in table C, Scenario 3 has the best performance in terms of Maintenance and heating costs (493,46 €) followed by Scenario 2 (521,03 €) and Scenario 1 (607,8 €). Therefore the stakeholders judged that the difference of attractiveness between scenario 3 and Scenario 2 is weak while Scenario 2 is strongly preferred to Scenario 1 one as it is showed in Figure 3.

For the criterion **Reduction of the CO_2 emissions** (Figure 4) we decided to apply an indirect comparison by comparing pre-defined performance levels (Table 2) according to the MACBETH methodology (Bana e Costa, 2001).



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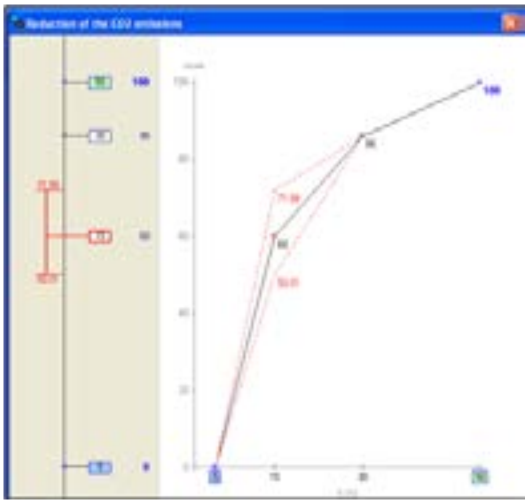

b

Figure 4. Reduction of the CO_2 emissions judgements.

In order to come to a sensible result, first the stakeholders identified an acceptability range of values for the reduction of the CO_2 emissions: between 20% and 30%. With this in mind, they answered to the pairwise comparisons stating that: 1) a 5% of CO_2 reduction is not acceptable because no one would operate a choice basing on this very low value; 2) a 15% of CO_2 reduction is considered interesting and therefore the differences of attractiveness between 5% and 15% is very strong; 3) a 30% of CO_2 reduction is considered the highest reachable level and the differences of attractiveness between 15% and 30% is strong; 4) a 50% of CO_2 reduction is obviously the best possible performance but it is considered as not reachable in the fixed temporal horizon of 15 years.

Once all the judgements have been inserted in the M-MACBETH software, the stakeholders decided to highlight a distance of 10 scores between the 5%

and the 15% performance (Figure 4b). The M-MACBETH software provides in fact a visual representation in form of thermometer of the distance between the elements in terms of attractiveness. This is to facilitate the stakeholders in understanding and modify their answers basing on the provided results. The value scores can be therefore changed while keeping fixed the remaining scores of other options and maintaining the compatibility with the matrix of judgements (Bana e Costa, 2010). Once answered all the pairwise comparisons required have been filled in, the overall results of the model were calculated (Figure 5).

Figure 5. Overall results.

Table of scores

Options	Overall	COST-INVEST	COST-RISCMANUT	RID CO2	RES
SCEN1	29.74	100.00	0.00	-17.14	0.00
SCEN2	52.09	60.00	66.67	5.71	66.67
SCEN3	61.03	0.00	100.00	68.57	100.00
[all upper]	100.00	100.00	100.00	100.00	100.00
[all lower]	0.00	0.00	0.00	0.00	0.00
Weights :		0.3300	0.4100	0.1900	0.0700

4_Discussion of the results and final remarks

This paper has presented a multicriteria application in order to structure a decision related to urban district energy development scenarios. The method used for this exercise is MACBETH approach because it allows interaction among stakeholders in order to quantifying value judgments about the elements of a finite set.

The assessment exercise was based on a focus group. As one can see from Figure 5, according to the answers provided during the focus group, the best alternative energy scenario for the district "Crocetta" turned out to be the Scenario 3 (61,03%) in a perspective of reducing the maintenance and heating costs and the CO_2 emissions by using clean fuels (i.e. pellet and biomass). Scenario 2 is also considered as an interesting scenario (52,09%) because it is economically affordable even if it does not reach the requested performances of CO_2 reduction. On the contrary, Scenario 1 turned out to be not good (29,74%) mainly due to the high heating costs and the very low possibility of reducing CO_2 emissions. Here the two "souls" of the participants emerge: the business operators emphasize the need for the economic viability of the investment, while the representatives of the public authorities advocate a reduction of the CO_2 emissions. This result is a sign of good balance with which the focus group was organised, and of the challenge in the decision-making process at the same time. This is to reconcile aspects that are currently antithetical.

It is evident that, in Italy, big changes in energy infrastructure can only take place if required by regulations or if effectively inserted in a logic of commercial advantage.

This application represents the first of a series of subsequent applications, which will be used to finalise the results. In fact, the sensitivity and robustness analyses of the results will be performed and new criteria will be added as suggested during the focus group, as the policies for heating demand reduction, will be considered.

Moreover, we currently consider the benefits arising from specific policies simply deriving them from the addiction of single buildings data. This critical aspect will be solved in further applications deriving the benefits also as possible synergic effects at a district level.

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