Multicriteria prioritization of policy instruments in buildings energy retrofit

Chiara D'Alpaos, Paolo Bragolusi**,*

key words: buildings, energy retrofit, energy efficiency, incentive policy, AHP

Abstract

Improvement of energy-efficiency in residential buildings is a crucial issue in Italy, where 55% of the building stock is older than 40 years and real estate assets are responsible for 33% of primary energy consumption. Consequently, the Italian residential sector offers considerable potential for reducing energy use and GHG emissions, particularly through energy-efficient renovations. Governments can introduce a wide range of policy instruments to encourage households in undertaking energy-efficient renovations: direct financial investments, regulatory instruments (e.g., performance and technology standards), economic and market-based instruments, support information and voluntary actions.

Since 2006, the Italian Government has introduced fiscal incentive programs to enhance energy efficiency in residential buildings. During the period 1998-2016 the cost for the Italian Government to due to fiscal incentives (i.e. tax deductions) was extremely high compared to tax revenues. Thus incentives turned out to be excessively costly and not cost-effective.

The design and implementation of incentive policies to buildings energy retrofit is a complex process involving a great number of decision variables and actors. Cost-effective incentive policies should prove capacity in stimulating investments, reducing social and environmental costs and promoting innovation. This complexity is exacerbated in the presence of stringent public budget constraints and lack of financial resources.

In order to favor the implementation of cost-effective retrofit strategies, the policy-maker must take into consideration along with buildings age and construction materials, social costs and benefits, EU and national targets, and environmental concerns. In this context, where multiple objectives need to be pursued, multiple criteria approaches provide a methodological framework to address the complexity of economic, physical, social, cultural and environmental factors which characterize incentive policies. In this paper we propose a multi-criteria decision model to support the policy maker in ranking sustainable incentive policies. In detail, we provide an AHP model for multiple-criteria prioritization of policy instruments to foster investments in energy retrofit of existing buildings.

1. INTRODUCTION

Buildings built before 1990 represent in Italy the majority (89%) of the overall dwelling stock, and are responsible for the major quota (33%) of primary energy consumption (CRESME, 2012; ENEA, 2017a; Ministero dello Sviluppo Economico, 2017). During the last decade, the building sector showed a strong decline due to the economic crisis that erupted in 2008, and new constructions have become residual among building interventions: new constructions represent about 1% (on a yearly basis) of the entire building stock. Improvement of energy efficiency in residential buildings is a crucial issue in Italy, where the existing stock has become the biggest potential for energy savings and greenhouse gas (GHG) emissions reduction particularly through energy-efficient renovations (Artola *et al.*, 2016; Conticelli *et al.*, 2017). Ensuring rapid and effective actions of deep energy renovations of existing buildings has thus drawn great attention by the Italian Government and Institutions in order to achieve EU-wide targets and policy objectives for the period between 2020 and 2030.

In 2017, the National Agency on new technologies energy and sustainable development (ENEA) reveals in fact that primary energy consumption in Italy in 2015 was of about 156.2 Mtoe and that demand/consumption in the residential sector increased by 10% compared to 2014, and amounted to 32.5 Mtoe. In compliance to the achievement of EU 2030 targets on GHG reductions, Italy is expected to save on primary energy a minimum quota of 25.8 Mtoe in the 2014-2020 period (ENEA, 2017a).

In order to implement the recast Directive 2010/31/EU, better known as Energy Performance of Buildings Directive (EPBD), and in accordance with the 2017 National Energy Strategy (SEN), the Italian Government aims to: a) reinforce actions that can impact the unexploited high energy saving potential in the building sector, and strengthen control and sanction mechanisms; b) introduce policy instruments for the implementation of energy efficiency measures in public administrations; c) stimulate energy planning and sustainable urban development, by introducing innovative models of urban planning and energy flows, grid efficiency, and upgrading and energy retrofit of the building stock; d) adopt plans for sustainable development of renewable energy sources.

Nonetheless, the current buildings renovation rate is around 2%, and most of energy retrofit actions generate little energy savings ranging from 20% to 30%, with an exploited potential of at least 60% (Atanasiu and Kouloumpi, 2013; BPIE, 2015; Building Stock Observatory, 2018).

This evidence suggests that current policies and industry initiatives are inadequate to foster investments in buildings energy retrofit, and that energy retrofitting interventions are still too limited for effectively reducing energy consumption in existing buildings. In addition to technical, financial and social barriers, and to ownership and occupancy structure, which strongly influence the feasibility and depth of cost-effective renovations, it is noteworthy that homeowners are often reluctant to renovate, because of capital constraints and uncertainties on energy savings, financial returns, and contractors' reliability (Wilson et al. 2015; Conticelli et al. 2017; Wilson *et al.*, 2018).

To encourage households in undertaking energy-efficient renovations, Governments can introduce a wide range of policy instruments: direct financial investments, regulatory instruments (e.g., performance and technology standards), economic and market-based instruments, support information and voluntary actions (Lee and Yik, 2004; Atanasiu *et al.*, 2014).

Since 2006, the Italian Government has introduced fiscal incentive programs to enhance energy efficiency in residential buildings. During the period 1998-2016, the cost for the Italian Government to due to fiscal incentives (i.e., tax deductions) was about 108.7 billion Euros and tax revenues amounted to 89.8 billion Euros. The final balance is thus negative: 18.9 billion Euros (nearly 1 billion Euros per year) and incentives turned out to be excessively costly and not cost-effective (ENEA, 2017b).

The design and implementation of incentive policies to buildings energy retrofit is a complex process, involving a great number of decision variables and actors. Incentive policies should prove capacity in stimulating investments, reducing social and environmental costs and promoting innovation. This complexity is exacerbated in the presence of stringent public budget constraints and lack of financial resources.

In order to favor the implementation of cost-effective retrofit strategies, the policy maker must take into consideration along with buildings age and construction materials, social costs and benefits, EU targets, and environmental concerns. In this context, where multiple and often conflicting objectives need to be pursued, multiple criteria approaches provide a proper theoretical and methodological framework to address the complexity of economic, physical, social, cultural and environmental factors, which characterize the design of incentive policies to buildings energy retrofit.

In this paper we propose an application-driven methodological framework to support the policy maker in the identification and prioritization of sustainable incentive policies.

In detail, by combining group decision making and Value Focused Thinking approaches, we provide a multiple criteria decision model, based on the Analytic Hierarchy Process (AHP), for the prioritization of policy instruments aimed at boosting investments in buildings energy retrofit and promoting energy efficiency in existing buildings. To structure the decision problem, we conducted an extensive literature review and interviewed a pool of experts, who represent different groups of stakeholders, by implementing a Delphi survey process.

The remainder of the paper is organized as follows. Section 2 reviews policy instruments adopted at EU level; Section 3 presents the methodological framework by illustrating the problem structuring and method; Section 4 describes the model and discusses results; Section 5 concludes.

2. INCENTIVE POLICIES

To reduce GHG emissions associated with the residential sector, in recent years, many EU countries have implemented incentive policies to encourage energy-efficiency upgrades and retrofit. These upgrades usually include specific home renovations, such as insulation, and equipment replacement or installment, such as high-efficiency heating and cooling systems (Alberini and Bigano, 2015; Evola and Margani, 2016; Conticelli *et al.*, 2017)[1]. The

[1] The Energy Performance of Buildings Directive (EPBD), together with the Energy Efficiency Directive (EED), the Renewable Energy Directive (RED), the Ecodesign Directive and Energy Labelling are the key pieces of EU legislation relating to long-term improvements in the energy performance of the European building stock.

extent to which the potential reduction of energy consumption in existing buildings is accomplished depends on renovation rates and depths. Incentive policies needs consequently to be successful in overcoming barriers to buildings energy retrofit, which can be grouped, as in Artola et al. (2016), into financial barriers (e.g., renovation costs, access to finance, low energy prices), technical barriers (e.g., lack of technical solutions, lack of knowledge by professionals), process barriers (e.g., supply chain fragmentation), regulatory barriers (e.g., uncertain ambition of performance requirements), and awareness barrier (e.g., lack of awareness on renovation benefits).

Except for direct financial investments, Governments can introduce a wide range of voluntary and mandatory policy initiatives to encourage buildings energy-efficient renovations. These policy measures can be grouped into three main categories: regulatory instruments, financial and fiscal instruments and information campaigns and labeling (Dresner and Ekins, 2006; Dongyan, 2009; Castellazzi *et al.*, 2016; Bottero *et al.*, 2019; Bonifaci and Copiello, 2019). The first category includes mandatory building codes, minimum energy performance standards, refurbishment obligations and energy efficiency obligation schemes. The second category comprises subsidies and financial instruments, grants for research (e.g., the Horizon 2020 Programme), development and innovation programs (e.g., programs for smart meter roll-out), tax incentives and Energy Service Companies. Instruments belonging to the last category encompass awareness raising and information campaigns, EU Energy Performance Certification and voluntary energy labeling schemes. Although economic theory suggests that if incentives and regulatory approaches are optimally designed, they produce the same result in terms of efficiency and welfare maximization, in practice, due to asymmetry of information, market incompleteness, and non-convexity of preferences, these policies entail different arguments for and against their successful implementation, that are synthetized in what follows.

1) Regulatory instruments

Regulatory instruments are effective in achieving the objective since they are mandatory (command and control approach), they do not generate direct costs (i.e., money expenditures) to the Government, though they represent a burden for homeowners, and they can be paired with other standards such as sanitation and safety. Building codes are present in all EU countries, therefore the implementation of regulatory policies might just require adaptation of existing codes. Nonetheless, their effectiveness may decrease due to enforcement problems, generated by difficulties in gaining political and social acceptance and by the need for an operational framework (e.g., setting the standards, accrediting auditors, etc.). Regulatory measures often require a long compliance period to gain support and this may result in potential delays of results.

At EU level, there are many examples of implementation of building codes and mandatory energy performance standards, such as the Germany's minimum energy performance standards for buildings "Energieeins parverordnung – EnEV" (Artola *et al.*, 2016).

2) Financial and fiscal instruments

Since the 1970s, the most common financial instruments, which have been introduced in Europe, include grants and subsidies, loans, and tax incentives (Atanasiu et al. 2014; D'Alpaos, 2017; Bottero *et al.*, 2019).

Subsidies and other financial instruments have been broadly adopted and, conditional to be well-designed, they can be effective and target low income households, thus contributing to solve fuel poverty issues. Nonetheless, to be set in force, a budget and an administrative body are required, and this in turn increase Government costs. In addition, an implementation risk is the attraction of recipients, who would have undertaken the investment anyway (i.e., free riders). To avoid misuse of these incentives, eligibility criteria must be properly defined and severe control is required, thus they can become hard and extremely costly to implement. Examples of subsidy programmes are the French Habiter Mieux programme and the German Reconstruction Credit Institute's (KfW) programme.

Tax incentive schemes are widely adopted in EU countries, mobilize private funding and can be applied both to renovations and products. By contrast, they can generate significant costs to the Government (due to a decrease in tax revenues), attract free-riders, and produce an over investment effect, analogous to the Averch-Johnson effect in regulated firms. Fiscal schemes related to purchase tax reductions or income tax incentives are implemented in Italy, France and Belgium (Artola *et al.*, 2016).

Finally, Energy Service Companies are attractive, because they use the money saved through investments in energy efficiency to pay off the initial capital investment, and they can overcome the split incentive barrier (i.e., landlord/tenant barrier). Nonetheless, they require major regulatory actions for tariffs assignment, and entail difficulties in determining energy savings, that cannot be directly measured.

3) Information campaigns and labeling

Information campaigns and labeling are highly socially and politically acceptable, can favor informed decisions about energy usage and living situation, and can improve relationships between landlords and tenants. Nonetheless, they appeal to individuals' sense of responsibility in order to encourage efficiency investments, therefore their effectiveness is questionable. Their effectiveness and efficiency are hard to prove, because it is very difficult to isolate, and demonstrate the causal nexus and influence of such schemes on energy consumption reduction.

There is strong evidence of awareness on renovation costs and burdens for property owners and landlords, authorities and tenants, whereas there is lack of awareness on benefits of renovations especially on those that are related to property value increase (Cerin *et al.,* 2014; Canesi *et al.,* 2016; De Ruggero *et al.,* 2017).

Figure 1 provides an overview of the main economic instruments set in place in 2013 in the EU (Economidou and Bertoldi, 2014).

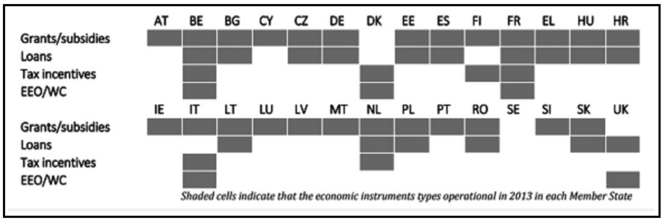

Figure 1 - *Main economic instruments set in place in the EU in 2013 targeting energy renovations*
(Source: Economidou and Bertoldi, 2014. Financing building energy renovations: current experiences & ways forward)

3. PROBLEM STRUCTURING AND METHOD

The assessment of public policies for potential implementation is a complex issue: stakes are high, decisions are costly to reverse, their consequences last for a long period and affect different stakeholders, whose support is fundamental for successful implementation. These stakeholders may in fact have different views on the problem. In this respect, decisions related to the implementation of policy instruments aiming at encouraging energy retrofit of existing buildings, ought to be addressed as a decision-making problem, where multiple criteria, and multiple conflicting objectives must be accounted for.

In literature, Multicriteria Decision Analysis (MCDA) methodologies are acknowledged as effective tools to address strategic decision problems (Belton and Stewart, 2001; Keeney, 2004; Schuwirth *et al*., 2012; Ishizaka and Nemery, 2013; Greco *et al*., 2017; Marinakis *et al*., 2017), such those related to energy efficiency issues.

Multicriteria Decision Making (MCDM) methods have been extensively proposed in literature to select green technologies and support design decisions for low carbon buildings (Dawood *et al*., 2013; Re Cecconi *et al*., 2017; D'Alpaos and Bragolusi, 2018; D'Alpaos and Bragolusi, 2019), but according to a recent literature review by D'Alpaos and Bragolusi (2018), there are fewer contributions on MCDA and MCDM approaches for policy evaluation (Haddad et al, 2017; Dias *et al.,* 2018; Kaya *et al.,* 2018; Chen and Lin, 2018; Katal and Fazelpour, 2018).

3.1 Problem structuring

Problem structuring is a fundamental phase in any decision problem, which involves multiple actors and perspectives, and conflicting interests to be reconciled. This phase becomes of paramount importance when alternatives are not designed in detail as in this case, in which policy specification can be costly and time consuming. Effective problem structuring is thus of critical importance, as the following phases are strongly affected by the structuring one (Belton and Stuart, 2010; Franco and Montibeller, 2011; Marttunen *et al.,* 2017).

Following Dias et al. (2018), to structure the decision problem, we addressed three main research questions:

1) What are the objectives to be pursued in designing policy instruments to foster existing buildings energy retrofit?
2) Which are the policies to be evaluated?
3) What type of decision *problematiqué*, among choice, ranking, sorting, description (Roy, 1996), is to be solved?

In this work, each objective corresponds to an evaluation criterion, identified to assess the impact of each policy instrument in the achievement of the objective under investigation.

To obtain the list of policy instruments and relative objectives, we conducted an extensive literature review, analyzed the EU-27 Building Policies and Programs (ENTRANZE Project 2012-2014) and interviewed academicians, industry experts and policy makers. The literature review, interviews and analysis of international experiences and Italian context also informed the identification of policy instruments to be evaluated, and the *problematiquè* to be solved. The suggested assessment result was the ranking of policy instruments, which allows for obtaining information solely on how alternative policies compare to each other, and not on their intrinsic merit (Dias *et al.,* 2018)[2].

Following a reference-based ranking approach, inspired by the seminal work in Roy (1996), policy instruments were evaluated on a qualitative basis, that built on expert judgments provided by different stakeholders[3] (Dias *et al.,* 2018). Differently from Dias et al. (2018), whose target result was an ordinal sorting of the alternatives, to aggregate expert judgments and solve the ranking problem, we implemented the Analytic Hierarchy Process (AHP).

In the impossibility of gathering the panel of experts and stakeholders in a single workshop and focus group, we involved them in a Delphi process survey, which allowed us to elicit opinions of respondents geographically dispersed, and ask elicitation questions in a qualitative way that did not assume expertise in MCDM.

We used Delphi survey to inquire about stakeholders'

[2]This ranking does not allow to establish if the implementation of the best alternative is worth and truly cost-effective.

[3] An accurate measurement and evaluation of the impacts (e.g., environmental, economic, social) of each policy is not in the scope of our work. In addition this evaluation would require an ambitious program of environmental, social and economic studies that is far beyond our currently available financial resources.

perspectives on the impact of each policy on each objective and the relative importance of objectives, and to perform pairwise comparisons of policy instruments.

3.2 Method

The AHP, proposed by Saaty in the Eighties (Saaty, 1980), is a well-established technique to address complex decisions with multiple objectives, incorporate multiple criteria in the decision framework and cope with criteria trade-offs (Saaty, 2000; De Felice and Petrillo, 2013; Grafakos *et al.*, 2015; Garbuzova-Schliftern, 2016; Banzato *et al.*, 2018).

The AHP builds on the hypothesis that the decision-maker is always able to express a preference and judge the relative importance of evaluation parameters (incomparability is not admitted), thus allowing the definition of an ordered set of preferences. The AHP is a theory of relative measurement of intangible criteria, and it grounds on an approach to relative measurement, according to which a scale of priorities is derived from pairwise comparison measurements (Saaty, 2016). It admits the possibility of evaluating quantitative and qualitative criteria and alternatives on the same preference scale.

In detail, the AHP decomposes the initial decision problem into several levels on a tree-like structure, by developing a hierarchy. It is in fact commonly agreed that the hierarchical structure provides users with a better focus on specific criteria and sub-criteria when allocating relative priorities/weights (Ishizaka and Labib, 2011). At the top of the hierarchy is placed the goal of the decision problem (e.g., ranking of policy instruments), whereas criteria and sub-criteria, which contribute to the goal, are placed at lower levels. Alternatives to be evaluated are placed at the bottom level (Saaty, 1980).

Once the hierarchy is structured, and supporting data (i.e., model input data) are collected for each alternative, it is possible to evaluate alternatives with respect to a finite number of attributes (criteria, sub-criteria, etc.).

Psychologists argue that it is easier to express one's opinion and value judgments on two sole elements than simultaneously on all elements; therefore attributes relative importance is determined through pairwise comparisons. Pairwise comparisons among elements of a comparable set are expressed in verbal judgments, which are converted into numerical values according to Saaty's fundamental scale (Saaty, 1980). In detail, verbal statements are converted into integers from one to nine (Table, 1) in a ratio scale, which has proven to be insensitive to small changes in the numerical judgments (Saaty, 1990).

Differently from interval scales, ratio scales do not require units in the comparisons and, according to Saaty (1994), represent the sole possible measurement if we want to aggregate measurements on different objects as in a weighted sum (Ishizaka and Labib, 2011).

By pairwise comparisons between attributes and alternatives, the decision-maker provides his/her subjective preference (relative importance) on the dominance of: a) one attribute over another with respect to the goal; b) one alternative over another with respect to each attribute. Pairwise comparisons of the elements in each level are conducted with respect to their relative importance towards their control/parent criterion (Saaty, 2000). When making comparisons between two elements belonging to one level of the hierarchy with respect to one element falling to the next level, the higher of the two is identified. The preference intensity of this element over the other is expressed in integers ranging from 1 (equal importance or preference) to 9 (extreme importance or preference), whereas the reciprocal value is used in comparing the smaller to the larger one. The pairwise-comparison procedure results therefore in square positive nxn reciprocal matrices of preferences, where the dominance coefficient a_{ij} represents the relative importance of the component on row i over the component on column j (Saaty, 1980; Saaty, 2000; Saaty and Peniwati, 2012).

Table 1 - *Saaty's fundamental scale (source Saaty, 1990)*

Importance	Definition
1	Equal importance
3	Moderate dominance
5	Strong dominance
7	Demonstrated dominance
9	Extreme dominance
2,4,6,8	Intermediate values

Priorities (i.e., weights) $w_1,\ldots w_n$ are derived for consistent or near consistent matrices and are such that w_i/w_j matches a_{ij}. Priorities are determined according to the eigenvalue approach to pairwise comparisons. The principal eigenvector is in fact the priority vector of a consistent nxn matrix A. It can be shown that the priority vector of a near consistent matrix, obtained by small and continuous perturbation of an underlying consistent matrix A, can be obtained as a perturbation of the corresponding principal eigenvector of A (Saaty, 2003).

As priorities are derived for consistent or near consistent matrices, Saaty introduces a consistency index CI to verify the consistency of pairwise comparison matrices (Saaty, 1977):

$$CI=(\lambda_{max}-n)/(n-1) \quad (1)$$

where λ_{max} is the maximum eigenvalue and n is the rank of the pairwise comparison matrix.

$IC < 0.10$ is usually considered as acceptable (Saaty, 1980).

Priorities $w_1,\ldots,w_n$ derived from pairwise comparison matrices are usually normalized in two different ways:

$$\Sigma_i w_i=1 \quad (2)$$

$$max_i w_i=1 \quad (3)$$

According to the normalization procedure, we obtain two versions of the AHP: the distributive mode ("Normals" priority vectors) that adopts normalization (2), and the ideal mode ("Ideals" priority vectors) that adopts normalization (3) respectively (Saaty and Vargas, 1993).

The global ranking of alternatives is then obtained via a weighted-sum, bottom-up, aggregation procedure throughout hierarchical levels (D'Alpaos and Bragolusi, 2019). The AHP adopts hierarchic composition to derive composite priorities of alternatives with respect to multiple criteria, starting from their priorities expressed with respect to each criterion (Saaty, 2003). Local priorities of criteria in a node are multiplied by local priorities of a corresponding parent criterion (Saaty, 1980). Hierarchical composition consists of "multiplying each priority of an alternative by the priority of its corresponding criterion and adding over all the criteria to obtain the overall priority of that alternative" (Saaty, 2003 p. 86).

Finally, sensitivity analysis is performed to validate the solution and test for rank reversal.

4. MODEL AND RESULTS

In order to structure the decision problem and provide the AHP relative model for ranking policy instruments, set to foster existing buildings energy retrofit in Italy, we conducted an extensive literature review on EU experiences of policy implementation and organized meetings with policy makers, regulatory authorities representatives and academicians. At the end of this structured process, which built on Value Focused Thinking principles (Keeney, 1992; Dias *et al.*, 2018), we obtained the following list of objectives considered to be relevant in the Italian context (Table 2):

- O1 Fuel Poverty Reduction;
- O2 Social/Political Acceptance Increase;
- O3 Private Investment Costs Reduction;
- O4 Government Costs Reduction;
- O5 Real Estate Assets Value Increase;
- O6 Primary Energy Consumption Reduction.

As above mentioned in Section 2.1, in this work each objective corresponds to an evaluation criterion, according to which the impact of each policy instrument in the achievement of the considered objective is assessed.

The literature review and the interviews also informed the choice of policy instruments to be evaluated, which accounted for international and national experiences (Table 2):

P1 Tax rebates

P2 Direct grants or subsidies;

P3 Preferential loan schemes;

P4 Energy standards setting;

P5 Training, education and qualification.

Although they are not potentially mutually exclusive, the above policy instruments were considered relevant by the stakeholders and experts consulted, under the hypothesis that the policy maker can start implementation (prioritize implementation) according to the final ranking.

Table 2 - *List of criteria/objectives and alternatives/ policy instruments*

Criteria/Objectives	Alternatives/Policy Instruments
O1 Fuel poverty reduction	P1 Tax rebates
O2 Social/political acceptance increase	P2 Direct grants or Subsidies
O3 Private investment costs reduction	P3 Preferential loans schemes
O4 Government costs reduction	P4 Energy standard setting
O5 Real estate assets value Increase	P5 Training, education and qualification
O6 Primary energy consumption reduction	

We briefly described the policy instruments and their pros and cons and discussed both the set of alternatives and objectives and validate the hierarchy (Figure 2), by dynamic discussion with a subset of stakeholders. Policy instruments were evaluated qualitatively, and the assessment built on judgments by 18 experts from different groups of stakeholders (Saaty and Peniwati, 2012; Dias *et al.*, 2018), who were interviewed in a Delphi survey process. Following Dias et al. (2018), the panel of experts represented three main perspectives: Government Perspective, Business Perspective and Knowledge Perspective. It consisted of policy makers, representatives of regulatory authorities and state-owned companies, as well as representatives of companies that operate in the building sectors, property and assets managers, representatives of tenants and homeowners associations, and finally of academicians and consultants.

The Delphi process was here implemented to ascertain, according to Saaty's fundamental scale, the opinion of different stakeholders on the impact of each policy on each objective, and the relative importance of objectives and alternatives. We firstly presented a draft of the questionnaire to the authors' research group and rewrote some questions and descriptions in a clearer way; then we run two rounds of the questionnaire and experts were encouraged to revise their earlier answers in light of the replies of other members of their panel.

At the end of the Delphi survey process, we obtained pairwise comparisons matrices from each member of the panel, and we aggregated individual judgments (Table 3) by calculating the geometrical mean, through which we synthesized individual judgments on a single pairwise comparison, as the representative judgment for the entire group (Xu, 2000; Grošelj and Zadnik Stirn, 2012; Dong and Saaty, 2014).

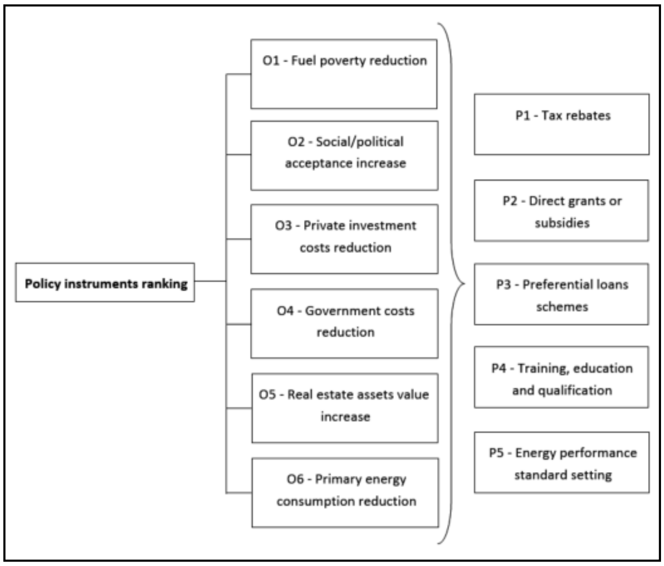

Figure 2 - *Hierarchy*

Table 3 - *Criteria/Objectives priority vector (Normals and Ideals)*

Criteria/Objectives ranking	Normals	Ideals
O2 Social/political acceptance increase	0.21561	1.00000
O1 Fuel poverty reduction	0.19404	0.89994
O4 Government costs reduction	0.17673	0.81966
O5 Real estate assets value increase	0.13876	0.64356
O6 Primary energy consumption reduction	0.13709	0.63580
O3 Private investment costs reduction	0.13777	0.63897

In the final phase of the process, we obtained the final priority vector and the prioritization of alternatives (i.e., policy instruments) with respect to the goal (Table 4).

Table 4 - *Ranking of alternatives and final priority vectors (Normals and Ideals)*

Alternatives/Policy instruments ranking	Normals	Ideals
P2 Direct grants or subsidies	0.33528	1.00000
P4 Energy performance standard setting	0.22683	0.67655
P3 Preferential loans schemes	0.15460	0.46111
P1 Tax rebates	0.15202	0.45340
P5 Training, education and qualification	0.13127	0.39153

According to priority vectors displayed in Table 3, social and political acceptance O2 is a major objective to pursue. Successful implementation of any policy or policy instruments is conditional to the consensus it is able to create upon. Fuel poverty reduction O1 is second in importance, as it represents a major concern for Governments, that need to guarantee access to energy to low-income households, especially in times of financial crisis, when there is a growing number of households at risk of not being able to keep warm at reasonable costs, due to their income. By contrast, private investment costs reduction O3 has lower priority compared to other objectives, as it has been proven in literature (D'Alpaos and Bragolusi, 2018; Bottero *et al*., 2019) that private investment costs can be offset by tangible and intangible benefits (e.g., energy costs saving, increase in occupants' well-being, etc.) gained by investors as a consequence of buildings energy retrofitting.

By direct inspection of Table 4, it emerges that direct grants or subsidies P2 are the preferable policy instruments when the main objective is to foster investments in existing buildings energy retrofit. This result is rather intuitive, as this policy has proven to be effective and has been broadly implemented in Europe. In addition direct grant or subsidies can target low-income households and boost the pursue of fuel poverty reduction, as well as they can gain maximum social and political acceptance. Nonetheless, they can increase Government costs and contribute to free-riding. Energy performance standard setting P4 is ranked as second, as it is effective, addresses the issue directly being mandatory and does not represent a cost for the Government, except that related to control and enforcement. This cost is indeed low compared to direct costs generated by subsidies and grants. Finally, this policy instrument, when implemented with respect to public housing, can also be very effective in reducing fuel poverty as it makes it mandatory to achieve high energy performance standards, that in turn imply low energy consumption.

By contrast, tax rebates P1 are placed at the lower level of the ranking, due to potential costs to the Governments (i.e., tax revenues decrease) and to administrative costs. Finally training and education and information campaigns P5 represents a "light approach" in that it is low cost in comparison to policies such as tax incentives and audits. Nonetheless, this policy instrument is weak, because it appeals to individuals' responsibility in order to encourage efficient investments.

5. CONCLUSIONS

We started our research motivated by a real-world application. We evaluated different policies designed to foster investments in buildings energy retrofit, which were not developed in sufficient detail to allow measuring their impacts quantitatively (e.g., cost-effectiveness analysis), and consequently, we solved a ranking decision problem.

The methodology developed in this work is based on the AHP, a well-established MCDM technique, which enables to address complex decisions with multiple objectives and incorporate multiple criteria in the decision framework. In our setting, each objective corresponds to an evaluation criterion, according to which it is assessed the impact of each policy instrument in the achievement of the objective under investigation.

To obtain the list of policy instruments and relative objectives, we conducted an extensive literature review, and interviewed academicians, representatives of regulatory authorities and policy makers. We identified 6 main objectives (i.e., fuel poverty reduction, social/political acceptance increase, private investment costs reduction, government costs reduction, real estate assets value increase, primary energy consumption reduction) and 5 policy instruments (i.e., tax rebates, direct grants or subsidies; preferential loan schemes; energy standards setting; training, education and qualification).

Judgments from 18 experts belonging to different groups of stakeholders were obtained via a Delphi survey process, that allowed us to ascertain values/preferences about policy impacts and criteria/objectives from three different perspectives: Government Perspective, Business Perspective and Knowledge Perspective. The policy instruments we took into consideration are not mutually exclusive or exclusive of other alternatives. They were selected for being a rather diverse set of policies deemed relevant by the stakeholders and experts consulted.

According to our findings, social/political acceptance is a major objective to pursue. Successful policy implementation is in fact conditional to the consensus it is able to gain. As far as the ranking of policies is concerned, our results show that direct grants or subsidies are the most preferable policy instrument. This policy has *de facto* proven to be effective and has been broadly implemented in Europe. In addition, as direct grants or subsidies can target low-income households, they can boost the pursue of fuel poverty reduction, and simultaneously they can gain maximum social and political acceptance.

A limitation of this work is that we do not address potential synergies among policies: policies were evaluated independently of each other. The combination of different policies is likely to be more effective that stand-alone instruments. Policy instruments might interact primarily to create awareness, trigger renovation, and ensure compliance and energy savings. The results of this study may nonetheless be considered as preliminary to the quantitative assessment of synergies between the most promising policies. To account for synergies among policies or combination of policies, an Analytic Network Process (ANP) might be implemented.

* **Chiara D'Alpaos,** *Dipartimento di Ingegneria Civile e Ambientale (ICEA), Università di Padova.*
e-mail: *chiara.dalpaos@unipd.it*
** **Paolo Bragolusi,** *Dipartimento di Ingegneria Civile e Ambientale (ICEA), Università di Padova.*
e-mail: *paolo.bragolusi@dicea.unipd.it*

References

Alberini A., Bigano A., *How effective are energy-efficiency incentive programs? Evidence from Italian homeowners*, Energy Economics, 52, 2015, pp. 576–585.

Artola I., Rademaekers K., Williams R., Yearwood J., *Boosting Building Renovation: What potential and value for Europe?*, European Parliament, Directorate General For Internal Policies Policy Department A: Economic And Scientific Policy, 2016, http://www.europarl.europa.eu/studies (last accessed on 18/01/2018).

Atanasiu B., Kouloumpi I., *Boosting Building Renovation. An Overview of Good Practices Renovation Requirements, Long-term Plans and Support Programmes in the EU and Other Selected Regions*, Buildings Performance Institute Europe (BPIE), Brussels, 2013.

Atanasiu B., Maio J., Staniaszek D., Kouloumpi I., Kenkmann T., Entranze, *Overview of the EU-27 building policies and programs. Factsheets on the nine Entranze target countries. Cross-analysis on Member-States' plans to develop their Building Regulations towards the Nzeb standard*, 2014, https://www.entranze.eu (last accessed on 2/2/2018).

Banzato D., Canesi R., D'Alpaos C., *Biogas and Biomethane Technologies: an AHP Model to Support the Policy Maker in Incentive Design in Italy*. In: Bisello A., Vettorato D., Laconte P., Costa S. (eds) Smart and Sustainable Planning for Cities and Regions. SSPCR 2017, Green Energy and Technology (9783319757735), Springer, Cham, 2018, pp. 319-331. DOI: 10.1007/978-3-319-75774-2_22.

Belton V., Stewart T.J., (2010) *Problem structuring and multiple criteria decision analysis*. In Ehrgott M., Figueira J.R., Greco S. (Eds.): Trends in Multiple Criteria Decision Analysis, International Series in Operations Research & Management Science, vol 142, Springer, Boston, MA, 2010, pp. 209-239.

Bpie (Building Performance Institute Europe), The BPIE data hub for the energy performance of buildings. In: BPIE data hub. (2015). https://www.buildingsdata.eu/ (last accessed on 18/01/2018).

Bonifaci P., Copiello S., *Incentive policies for residential buildings energy retrofit: An analysis of tax rebate programs in Italy*. In: Bisello A., Vettorato D., Laconte P., Costa S. (eds) Smart and Sustainable Planning for Cities and Regions. SSPCR 2017. Green Energy and Technology (9783319757735), Springer, Cham, 2018, pp. 267-279.

Bottero M., D'alpaos C., Dell'anna F., *Boosting investments in buildings energy retrofit: the role of incentives*. In: Calabrò F., Della Spina L., Bevilacqua C. (eds) New Metropolitan Perspectives. ISHT 2018. Smart Innovation, Systems and Technologies, vol 101. Springer, Cham, 2019, pp. 593-600. DOI: 10.1007/978-3-319-92102-0_63.

Building Stock Observatory, (2018). https://ec.europa.eu/energy/en/data-analysis/building-stock-observatory (last accessed on 18/01/2018).

Canesi R., D'Alpaos C., Marella M., *Forced sale values vs. Market values in Italy*, Journal of Real Estate Literature, 24(2), 2016, pp. 377-401.

Castellazzi L., Zangheri P., Paci D., *Synthesis Report on the assessment of Member States' building renovation strategies*, Publications Office of the European Union, 2016, https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/synthesis-report-assessment-member-states-building-renovation-strategies (last accessed on 2/2/2018).

Cerin P., Hassel L., Semenova N., *Energy Performance and Housing Prices*, Sustainable Development, 22, 2014, pp. 404-419.

Conticelli E., Proli S., Tondelli S., Integrating energy efficiency and urban densification policies: Two Italian case studies, Energy and Buildings 155, 2017, pp. 308-323.

Cresme, *Riuso 2012. Città, mercato e rigenerazione. Analisi del contesto per una nuova politica urbana*, CRESME, CNAP, ANCE, Roma, 2012. www.old.awn.it (last accessed on 30/11/2017).

Dawood S., Crosbie T., Dawood N., Lord R., *Designing low carbon buildings: a frame-work to reduce energy consumption and embed the use of renewables*, Sustainable Cities and Society, 8, 2013, pp. 63-71.

D'Alpaos C., *Methodological Approaches to the Valuation of Investments in Biogas Production Plants: Incentives vs. Market Prices in Italy*, Valori e Valutazioni, 19, 2017, pp. 53-64.

D'alpaos C., Bragolusi P., *Buildings energy retrofit valuation approaches: State of the art and future perspectives*, Valori e Valutazioni, 20, 2018, pp. 79-94.

D'alpaos C., Bragolusi P., *Prioritization of Energy Retrofit Strategies in Public Housing: an AHP mode*. In Calabrò F., Della Spina L., Bevilacqua C. (eds): New Metropolitan Perspectives. ISHT 2018. Smart Innovation, Systems and Technologies, vol 101, 2019, pp. 534-541. DOI: 10.1007/978-3-319-92102-0_56.

De Felice F., Petrillo A., *Absolute measurement with analytic hierarchy process: a case study for Italian racecourse*, International Journal of Applied Decision Sciences 6(3), 2013, pp. 209-227.

De Ruggiero M., Forestiero G., Manganelli B., Salvo F. *Buildings Energy Performance in a Market Comparison Approach*, Buildings, 7(1), 16, 2017.

Dong Q., Saaty T.L, *An analytic hierarchy process model of group consensus,* Journal of Systems Science and Systems Engineering, 23(3), 2014, pp. 362-374.

Dongyan L., *Fiscal and tax policy support for energy efficiency tretrofit for existing residential buildings in China's northerm heating region,* Energy Policy 37, 2009, pp, 2113-2118.

DRESNER S., EKINS P., *Economic Instruments to Improve UK Home Energy Efficiency without Negative Social Impacts*, Fiscal Studies 27(1), 2006, pp. 47-74.

Economidou M., Bertoldi P., Financing building energy renovations. Current experiences & ways forward, JRC Science and Policy Reports, Publications Office of the European Union, Brussels, 2014, https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/financing-building-energy-renovations-current-experiences-and-ways-forward (last accessed on 12/3/2018).

Enea, *Rapporto Annuale - Efficienza Energetica*, Analisi e Risultati delle Policy di Efficienza Energetica del Nostro Paese, 2017a, pp. 1-33. http://enerweb.casaccia.enea.it/enearegioni/UserFiles/RAEE_2017.pdf (last accessed on 20/12/2017).

Enea, *Rapporto Annuale 2017 - Le detrazioni fiscali del 65% per la riqualificazione energetica del patrimonio edilizio esistente*, 2017b, www.efficienzaenergetica.enea.it/allegati/Detrazioni-65-2017_.pdf (last accessed on 20/12/2017).

Evola G., Margani G. *Renovation of apartment blocks with BIPV: Energy and economic evaluation in temperate climate*, Energy and Buildings 130, 2016, pp. 794-810.

Ferreira F. A., Santos S. P., Dias V. M., *An AHP-based approach to credit risk evaluation of mortgage loans*, International Journal of Strategic Property Management 18(1), 2014, pp. 38-55.

Franco L.A., Montibeller G. *, Problem structuring for multicriteria decision analysis interventions*, John Wiley&Sons, Oxford, 2011.

Garbuzova-Schliftern M., Madlener R., *AHP-based risk analysis of energy performance contracting projects in Russia*, Energy Policy 97, 2016, pp. 559-581.

Grafakos S., Flamos A., Enseñado E.M., *Preferences matter: A constructive approach to incorporating local stakeholders' preferences in the sustainability evaluation of energy technologies*, Sustainability 7(8), 215, pp. 10922-10960.

Grošelj P., Zadnik Stirn L., Acceptable consistency of aggregated comparison matrices in analytic hierarchy process, European Journal of Operational Research, 223(2), 2012, pp. 417-4201.

Haddad B., Liazid A., Ferreira P., *A multi-criteria approach to rank renewables for the Algerian electricity system*, Renewable Energy, 107, 2017, pp. 462-472.

Ishizaka A., Labib A., *Review of the main developments in the analytic hierarchy process*, Expert Systems with Applications 38, 2011, pp. 14336-14345.

ISTAT, 15° *Censimento della popolazione e delle abitazioni*, http://www.istat.it/it/censimento-popolazione/censimento-popolazione-2011, ultimo accesso 1/1/2018.

KEENEY R.L., *Value-focused thinking*. Harvard University Press, Cambridge (MA), 1992.

LEE W.L., YIK F.W.H., Regulatory and voluntary approaches for enhancing building energy efficiency, Progress in Energy and Combustion Science, 30(5), 2004, pp. 477-499.

MARTTUNEN M., LIENERT J., BELTON V., *Structuring problems for Multi-Criteria Decision Analysis in practice: A literature review of method combinations*, European Journal of Operational Research, 263, 2017, pp. 1-17.

MINISTERO DELLO SVILUPPO ECONOMICO, *Relazione annuale sull'efficienza energetica - Risultati conseguiti e obiettivi al 2020*, Direzione generale per il mercato elettrico, le rinnovabili e l'efficienza energetica, il nucleare, 2017, pp. 1-28.

RE CECCONI F., TAGLIABUE L.C., MALTESE S., ZUCCARO M., *A multi-criteria framework for decision process in retrofit optioneering through interactive data flow*, Procedia Engineering, 180, 2017, pp. 859-869.

ROY B., *Multicriteria Methodology for Decision Aiding*, Kluwer Academic, Dordrecht, 1996.

SAATY, T.L., *A scaling method for priorities in hierarchical structures*, Journal of Mathematical Psychology, 15, 1977, pp. 234-281.

SAATY T.L., *The analytic hierarchy process: planning, priority setting, resource allocation*. McGraw-Hill, New York, 1980.

SAATY T.L., *The Analytic Hierarchy Process in Conflict Management*, The International Journal of Conflict Management, 1(1), 1990, pp. 47-68.

SAATY T.L., VARGAS L.G., *Experiments on rank preservation and reversal in relative measurement*, Mathematical and Computer Modelling,17(4-5), 1993, pp. 3-18.

SAATY T.L., *Fundamentals of decision making and priority theory with the analytic hierarchy process*, RWS Publications, Pittsburgh, 2000.

SAATY T.L., *Decision-making with the AHP: Why is the principal eigenvector necessary*, European Journal of Operational Research, 145, 2003, pp. 85-91.

SAATY T.L., PENIWATI K., *Group Decision Making Drawing Out and Reconciling Differences*, RWS Publications, Pittsburgh, 2012.

SAATY T.L., *The Analytic Hierarchy and Analytic Network Processes for the Measurement of Intangible Criteria and for Decision-Making*. In: Greco S., Ehrgott M., Figueira J. (eds) Multiple Criteria Decision Analysis. International Series in Operations Research & Management Science, vol 233. Springer, New York, NY, 2016, pp. 363-419.

XU, Z., *On consistency of the weighted geometric mean complex judgment matrix in AHP*, European Journal of Operational Research, 126(3), 2000, pp. 683-687.

WILSON C., CRANE L., CHRYSSOCHOIDIS G., *Why do homeowners renovate energy efficiently? Contrasting perspectives and implications for policy*, Energy Research and Social Science, 7(128), 2015, pp. 12-22.

WILSON C., PETTIFOR H., CHRYSSOCHOIDIS G., *Quantitative modelling of why and how homeowners decide to renovate energy efficiently*, Applied Energy 212, 2018, pp. 1333-1344.