Local energy efficiency programs: A monitoring methodology for heating systems

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1. Introduction

The European goals for the years 2020 (European Parliament, Directive 2009/28/EC, 2009) and 2050 (ECF, 2010) along with other European Directives focused on energy efficiency, like the EPBD Recast (European Parliament, Directive 2010/31/EU, 2010) and the Energy Efficiency Directive (European Parliament, Directive 2012/27/EU, 2012), are clear signs of an increasing commitment to energy sustainability at continental level. Italy recently introduced new programs like the National Action Plan for Energy Efficiency (Ministero dell'Ambiente, 2011) and the National Energy Strategy (Parlamento Italiano, D.I. 04/03/2013, 2013). Despite the substantial improvements made at the technological and regulatory level in recent years, a significant potential for energy efficiency remains still unexploited (IEA, 2008a, 2008b).

The statistics regarding energy consumption highlights how buildings in Europe (residential and tertiary) are responsible for about the 40% of the primary energy consumption (BPIE, 2011). New and existing buildings are key components to tackle in view of future energy and environmental goals, because of their very high potential and the general implications related to the efficiency of the built environment (Wilkinson, Smith, Beevers, Tonne, & Oreszczyn, 2007). Italian buildings account for the 35% of the overall national energy balance (ENEA, 2012). Residential buildings represent the 57% of this quantity and space heating alone is responsible for about the 66% of energy consumption in this sector. Despite the large availability of efficient "off the shelf" technologies, the cost of efficiency measures remains, in many cases, one of the most important barriers, as underlined in the EPBD recast (European Parliament, Directive 2010/31/EU, 2010), which states that "energy performance requirements for buildings or building units are set with a view to achieving cost-optimal levels". Beside costs, there exist also various types of non-technical barriers, related, for example, to non-uniform regulations between national and local government, rapidly changing requirements, inability to attract investments, management issues, etc. At the policy making level, the importance of the heating sector can be recognized also in the Directive 2009/28/EC on the promotion of the use of energy from renewable sources and in the Directive 2004/8/EC on the promotion of cogeneration. In fact, while at National and

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Nomenclature

Variables and parameters

C	cost
c	cost per unit of energy
DPB	discounted payback
E	energy
f	emission or conversion factor
m	mass
η	efficiency
NPV	net present value
r	discount rate of the investment
v	value
w	relative weight

Subscripts and superscripts

em	emission
$fuel$	fuel
i	index
inv	investment cost
max	maximum
N	project lifetime
$O\&M$	operation and maintenance
th	thermal
y	year

Regional level the more diffuse conventional systems, fossil fuel boilers, have a required minimum performance level (D.G.R., 2007; Parlamento Italiano, D.P.R. 59/2009, 2009), an increasing emphasis should be put on the role of technologies based on renewable energy sources combined with high-efficiency technologies, to meet the heat demand of the built environment more sustainably in the future (Pardo Garcia, Vatopoulos, Krook-Riekkola, Perez Lopez, & Olsen, 2012).

Indeed, policies should be aimed at a synergistic effect (i.e. exploiting systems of efficient technologies as a mean to achieve ambitious goals, specific for different sectors, but clearly quantifiable by means of indicators) and supplemented by continuous planning, monitoring and adjustment. These steps clearly require an interaction among governmental institution, policy makers, construction industry, investors, owners and occupants of buildings. Basically, two fundamental points of view have to be considered, the societal one, encompassing cost of "externalities" (climate change, pollution, etc.), and the end-user's one encompassing reasons that can prevent efficiency investment (technical barriers, lack of information and motivation, risks and uncertainties related to the investment, etc.).

In this framework, the paper aims to describe, by means of a case study, a methodology to monitor and evaluate the results of energy efficiency programs, addressing the following issues:

1. effectiveness of the programs with respect to multiple objectives;
2. relevance of the subsidy mechanism with respect to the objectives considered;
3. simplicity, transparency and ease of implementation of the monitoring and evaluation process;
4. fundamental insights and generalization.

The following section presents more specifically the motivation of the research.

2. Research motivation

Energy policy, among other things, should be aimed at learning effective schemes to enhance the diffusion of efficient technologies and practices. In this sense, national and local governmental institutions have to develop a specific know-how to support effectively the transition towards a more sustainable energy paradigm. Therefore, research and development in the energy sector has to be performed both at the technological level and at the system level. In the building sector, the necessity to accelerate the introduction of innovative technologies is rapidly shifting the focus on global optimality of design strategies and competitiveness of solutions (Aste, Adhikari, & Manfren, 2013; European Commission, 2011a, 2011b; Georges, Massart, Van Moeseke, & De Herde, 2012; KB, 2011; Mahapatra & Gustavsson, 2008; Nässén & Holmberg, 2013).

In any case, the technological and normative development has to be necessarily complemented by a monitoring process and policies have to be adjusted coherently as the characteristics of the reference system evolve (Steinbach et al., 2013). We assisted in recent years at a proliferation of energy efficiency programs at European, Italian and local level. However, programs have to be correctly designed from the beginning in order to ensure consistency with the administrative procedures in terms of information management and ease of implementation, avoiding time consuming and expensive analysis procedures, in particular in the verification and monitoring phases.

For this reason, the results of this research are described by means of environmental, energy and economic performance indicators, in order to address not only the outcomes of local energy policy actions, but also to set the basis for future local policies in which there will be the necessity to compare in a transparent way larger portfolios of technological options and different scales, from single buildings to communities and territories. The case studies presented are existing heating systems which have been retrofitted by substituting the diesel boilers with efficient natural gas boilers and which received a subsidy from Lombardy Region. The details on the case studies and the specific thematic areas and indicators considered are described in detail in Section 3.

3. Monitoring campaign of a local energy efficiency program for heating systems

Lombardy Region in the last years promoted several programs and projects such as "Action Plan of Energy", "Strategic Plan of technologies for Energy Sustainability In Lombardy", "Plan for Sustainable Lombardy", "Factor 20" and "Trend". The monitoring of energy demand and supply, the environmental impact and the degree of achievement of European targets is presented by an information system which stores all the fundamental statistics collected at regional level (Finlombarda S.p.a. CENED; Finlombarda S.p.a. CURIT; Regione Lombardia; SIRENA).

At present, the total primary energy consumption of Lombardy Region is about 29.3 MTEP; this value accounts for the primary energy consumption related to the use of fuels and electricity. If we consider the energy losses related to transformation and transportation processes, it corresponds to about 24.9 MTEP of total energy supply to end-users, able to satisfy the following demands: 10.4 MTEP for the civil sector; 7.6 MTEP for the industrial sector; 6.6 MTEP for transportation and 0.4 MTEP for agriculture. These statistics clearly underline the importance of the built environment in the overall energy balance (Factor20, 2011).

Lombardy Region joined, with the approval of the "Accordo di Programma Quadro in materia di Ambiente e Energia" (Framework Program Agreement in the field of Environment and Energy), a national program launched in 1999 (year of the first call) by the Italian Ministry of the Environment, focused on regional scale programs for energy efficiency measures and renewable energy technologies. Lombardy Region developed a program for the provision of subsidies to public and private investors, determined by means of an open competition based on rules that were specific to the different topics of the framework. These topics were:

- efficient natural gas heating systems;
- district heating and biomass plants;
- solar thermal plants;
- low environmental impact biofuels;
- hydrogen experimental facilities;
- sustainable mobility;
- energy efficiency in the building sector.

After the realization of the projects subsidized in the overall program, the Italian Ministry of the Environment and Lombardy Region financed a monitoring campaign, carried out by Politecnico di Milano, with the scope of critically analysing the results achieved and getting useful insights for future programs and projects.

In this paper the monitoring and analysis process performed within the topic "Efficient natural gas heating systems" is presented. Natural gas boilers, in particular condensing ones, represent a well-established technology that can offer significant energy and emissions savings in the residential and commercial buildings at the national (Aste & Del Pero, 2012; Aste, Adhikari, Compostella, & Del Pero, 2013) and European level. More in general, the switch from oil derived fuels to less polluting fuels (e.g. natural gas) can open up new scenarios in terms of efficiency, competitiveness and reduced environmental impact, with the introduction of distributed generation technologies (Carpaneto, Chicco, Mancarella, & Russo, 2011a, 2011b; Gu et al., 2014; Piacentino, Barbaro, Cardona, Gallea, & Cardona, 2013). In the following paragraph, the "state of the art" for heating systems at the national and regional level is introduced in order to understand the conditions in which the program and the monitoring campaign took place. After that, the specific methodology used for data collection and analysis is described.

3.1. Heating systems status in Italy and Lombardy region

In Italy there are today approximately 22,802,000 heating systems, 7,450,000 of which are centralized systems and the majority of them are fuelled by natural gas (CRESME, 2011). Lombardy Region alone accounts for 1,340,000 residential buildings and represents the 12% of the total national building stock (ISTAT); Lombardy is the Italian region with the largest number of buildings and population. In Lombardy, the highest concentration is present of both individual and centralized heating systems at national scale: respectively the 21.9% and the 16.1% of the total plants in Italy. Therefore, the most common heating systems in Lombardy, according to the 2010 statistics, were the individual ones, similarly to the other Italian regions (CRESME, 2011).

The most important fuel in terms of end-use is natural gas, and its consumption shows the following breakdown: 36.9% for the tertiary sector, 31.4% for the industrial sector and 31.2% for the residential sector (ENEA, 2012). From the climate point of view, the Italian territory is divided into 6 climate zones by law (Parlamento Italiano, D.P.R. 412/93, 1993), dependent on the Degree-Days (DD) number, from hottest to coldest (A to F). Lombardy is mainly in zone E and in part in zone F and collocates itself among the coldest regions in Italy (being located on the northern border). Therefore, heating demand is a fundamental component of the regional primary energy balance, with the 32% of the overall final energy uses (SIRENA).

Table 1
Parameters for subsidy calculation.

Range	Heating power installed	Subsidy
1	35–200 kW	20 €/kW
2	200–500 kW	4000 € + 10 €/kW for every kW above 200 kW
3	Over 500 kW	7000 € + 5 €/kW for every kW above 500 kW

In 2004 (at the beginning of the program), the 60% of heating demand for the residential and tertiary sector in Lombardy was covered by natural gas while the 13% by diesel fuel and the remaining part was covered by electricity and other sources (including renewable ones); in 2008, these percentages were respectively 65% and 8% (ENEA, 2012), showing a rapid switch to natural gas, determined by the urge for energy efficiency, economic competitiveness of service and reduced emissions. At present, the natural gas network is evenly distributed in Lombardy, with the exception of the Alpine area where its implementation is more costly and the population density is lower.

With respect to the heating plant typology, from 2001 to 2011 there was an overall increase of the 42% of the centralized natural gas heating systems with a reduction of centralized diesel ones of 26%. The percentage of increase of the individual heating systems fed by natural gas is 24%, with a decrease of diesel ones of 38% (Cirillo, Bobbio, Rocca, & Franci, 2013). The statistics highlight an increasing diffusion of centralized heating systems and a decrease of independent installations.

3.2. Dimension and time frame of support programs

As anticipated, the program focuses on the replacement of diesel boilers with efficient natural gas ones. The eligible investment costs where the ones related to the boiler and the additional components (including heat exchangers, pumps, pipes, exhaust system, connection to the natural gas network, etc.). The first call dates back to August 2004 (D.G.R., 2004), while the second to October 2005 (D.G.R., 2005). In both calls, the amount of subsidy given was determined based on the criteria reported in Table 1, depending on the total heating power to be installed and corresponding to the values shown in Fig. 1.

The technologies subsidized were boilers with heating power greater or equal to 35 kW, with a minimum rating of four stars, in accordance with the European Directive 92/42/EEC (European Parliament, Council Directive 92/42/EEC, 1992), as implemented at the national level (Parlamento Italiano, D.P.R. 660/96, 1996). The total number of plants subsidized was 1488, corresponding to an

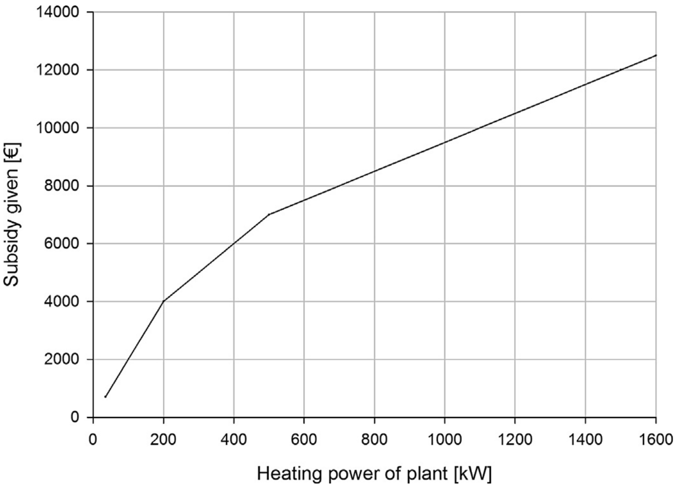

Fig. 1. Subsidy as a function of installed heating power of plant.

Table 2
Thematic areas and indicators for data analysis.

Thematic areas	Description	Simple indicators	Composite indicators
Cost for the public administration	The total cost for the public administration (net cost without management)	Cost of the project [€]	
Participants	The type of participants have to be identified	Distribution of participants (private/public) [%]	
Transparency	Transparency is linked to the mode of access to subsidy, data availability and completeness.	Completeness and coherency of the available data [%]	
Energy and environmental system characterization	The technical data that is necessary to characterize the system from the energy and environmental point of view.	Heating power [kW] Fuel consumption [kWh] Energy conversion efficiency [–] Emission factors [g/kWh]	
Effectiveness	Effectiveness of investments can be measured with respect to the energy and emissions saved.		Primary energy saving [TOE] CO_{2eq}, NO_x and SO_2 emission saving [t]
Cost/effectiveness	Cost/effectiveness is evaluated in order to compare different types of interventions and technological solutions in relative terms from a techno-economic point of view.	Specific heating power cost [€/kW]	Specific primary energy saving cost [€/TOE] Specific CO_{2eq}, NO_x and SO_2 emission saving cost [€/t]
Relation with the market	The comparison involves the relation between the investment and the subsidy given and the average market price for the energy and emission savings	Ratio between investment (market price) and subsidy [%]	Market price of energy saving [€/TOE] Market price of CO_{2eq} saving [€/t]
Competitiveness	The competitiveness is evaluated from the point of view of the investor, using general economic indicators.		Net present value, *NPV* [€] Discounted payback, *DPB* [y]

installed heating power capacity of 465 MW, and 7,763,310 € of subsidies given.

Based on the availability and completeness of data, the total capacity monitored and analyzed in the research was 335 MW (72%, 335 MW over 465 MW), corresponding to 1100 plants (74%, 1100 over 1488) and 5,683,555 € of subsidies (73%, 5,683,555 € over 7,763,310 €). The data collected show a great variability of the investment budget, depending clearly on the size of the heating system but also on the type of components replaced and included by participants in the investment budget presented in the competition. The analysis of the distribution of participants showed clearly a predominance of private institutions over public institutions, with a percentage respectively of 99% and 1%.

3.3. Data collection and construction of the datasets

The collection of data is the necessary starting point for a monitoring campaign, because a clear and uniform organization of information represents a pre-requisite for the analysis process. The dataset assembled in the monitoring process consisted of 6 fundamental sections:

1. indexing data (univocal identification of the documents);
2. geographical data (territorial distribution of interventions);
3. technical data (energy and environmental performance);
4. economic data (costs and subsidies);
5. environmental data (environmental performance);
6. administrative data (program management).

The dataset was populated with the data collected and complemented by the indicators calculated according to assumptions that will be introduced in detail later. The different performance indicators were grouped in the following general thematic areas:

- cost for the public administration;
- participants;
- transparency;
- energy and environmental system characterization;
- effectiveness;
- cost/effectiveness;
- relation with the market;
- competitiveness.

It is necessary to draw a distinction between simple and composite indicators, because the former were directly determined based on the data collected, while the latter were calculated introducing some fundamental assumption that will be described later in this section. The description of the different thematic areas and the different indicators chosen is reported in Table 2.

First of all, the basic data for the analysis are the ones related to technologies and end-users (energy demand, conversion and emissions):

1. nominal heating power;
2. fuel consumption;
3. energy conversion efficiency;
4. emission factors.

However, the most valuable indicators in the evaluation of the program are mainly composite ones, such as:

- primary energy and emissions' savings (CO_{2eq}, NO_x and SO_2);
- primary energy and emissions' savings normalized with respect to subsidy (cost/effectiveness);
- net present value (*NPV*) and discounted payback (*DPB*).

The amount of primary energy and emissions' savings have been calculated for a time frame that coincides with the expected lifetime of the technology, equal to 15 years (CIBSE, 2009; COWI, 2011), in accordance to the legislation for the harmonization of the lifetimes of these technological systems in European countries. From the collected data, it emerged that the condensing boilers are the predominant choice, with a percentage of 97% on average, while efficient conventional (non-condensing) ones were chosen

Table 3
CO_{2eq}, NO_x and SO_2 emission factors.

Emission type	Unit	Diesel	Natural gas
CO_{2eq}	g/kWh	264.21	199.91
NO_x	g/kWh	0.216	0.048
SO_2	g/kWh	0.36	0.0018

only in the 3% of the interventions. The assumptions on the average energy conversion efficiency of boilers, necessary to calculate the value of thermal demand and compare the result with different type of plants, derive from an estimate of the realistic average operating conditions (type of end-use) and types of technologies, following a methodology used in previous case studies (Aste & Del Pero, 2012; Aste, Adhikari, Compostella, et al., 2013). The values (referred to LHW) obtained for the average conversion efficiency are respectively 81% for conventional diesel boilers, 85% for the new conventional natural gas boilers and 96% for new condensing natural gas boiler. Primary energy and emissions of CO_{2eq}, NO_x and SO_2 are calculated according to the following formulas (EN, 2008b):

$$E_{fuel,y} = \frac{E_{th,y}}{\eta_{th}} \tag{1}$$

$$E_{P,fuel} = \sum_{y=1}^{N} E_{fuel,y} f_{P,fuel} \tag{2}$$

$$E_{em,fuel} = \sum_{y=1}^{N} E_{fuel,y} f_{em,fuel} \tag{3}$$

The primary energy factors for fuels are assumed to be equal to 1 (i.e. primary energy losses of the whole energy chain located outside the building system boundary are not taken into account) (EN, 2008b), following the current Italian building energy certification scheme (UNI, 2008). The CO_{2eq} emission factors for the fuels (natural gas, diesel) depend simply on the type of fuel (EN, 2008b), while the NO_x and the SO_2 emission factors are dependent both on the fuel and on the specific technology (ARPA; SIRENA). The emission factors assumed are reported in Table 3.

It is worth noticing that pure natural gas doesn't contain sulphur (it would result theoretically in a 100% reduction of SO_2 emission and a emission factor equal to 0), but this value has been assumed considering the factors normally used for this type of evaluations at the regional level (SIRENA), which consider the possibility of traces of SO_2. Primary energy and emission savings can then be normalized with respect to the subsidy given (i.e. amount of public resources used in the support program, with respect to the result obtained, cost/effectiveness ratio of the measure). Finally, in order to consider the end-user's perspective in the evaluation, the economic parameters net present value (*NPV*) and discounted payback (*DPB*) (EN, 2008a) have been calculated for all the investments according to the following formulas:

$$C_{fuel,y} = E_{fuel,y} c_{fuel,y} \tag{4}$$

$$NPV = C_{inv} + \sum_{y=1}^{N} \frac{C_{fuel,y} + C_{O\&M,y}}{(1+r)^y} \tag{5}$$

In general, *NPV* accounts fir the initial investment cost and the annual operation and maintenance costs, considering the time value of money (standard present worth analysis) to construct the cumulative cash flow (year by year). *DPB* represent the amount of time in which the cumulative cash flow (*NPV* formula) for a project becomes equal to 0 (i.e. the investment starts to generate profit, the cumulative cash flow becomes positive) and therefore the amount of time needed to recover the initial investment.

Table 4
Description of the assumption for the economic analysis.

Parameter	Unit	Value
Diesel cost	€/kWh	0.09
Natural gas cost	€/kWh	0.06
Rates of annual increase of diesel cost	%	4.0
Rates of annual increase of natural gas cost	%	4.5
Discount rate of the investment (r)	%	4
Project lifetime (n)	y	15
Lifetime of technologies	y	15

Table 5
Number of generators, plants, capacity installed, investment cost and subsidy with respect to power range of plants.

Range	Plants –	Capacity installed MW	Investment cost €	Subsidy €
35–200 kW	461	62.6	11,544,191	1,246,940
200–500 kW	512	157.8	19,565,969	2,785,560
>500 kW	127	114.7	9,740,687	1,606,055
Total	1100	335.0	40,850,846	5,638,555

In this specific case, the cumulative cash flow is the difference between the baseline (diesel boiler system) and the efficient heating system (natural gas boiler system). The *DPB* represent the moment in which the efficient system recovers its higher initial investment and start to generate positive cash flow (i.e. money saved over the baseline system).

The costs of diesel and natural gas were derived, respectively, from data given by the Italian Ministry for Economic Development (Ministero dello Sviluppo Economico) and by the Authority for Electricity and Gas (AEEG). The fundamental assumptions for the economic analysis are reported in Table 4.

4. Results and discussion

The data are subdivided with respect to the power ranges used for the calculation of the subsidy and reported in Table 1. This subdivision was maintained to highlight the possible scale effects on economic parameters. The fundamental data analyzed, such as the number of plants, the heating power capacity, the investment cost and the subsidy given are reported in Table 5. Fig. 2 shows the proportions in terms of percentage of heating power capacity, investment cost and subsidy for the plants and highlighting the importance of the medium size plants, in terms of total result.

The overall result, in terms of primary energy saving, amounts to approximately 72,648 TOE in 15 years with a 15% reduction with

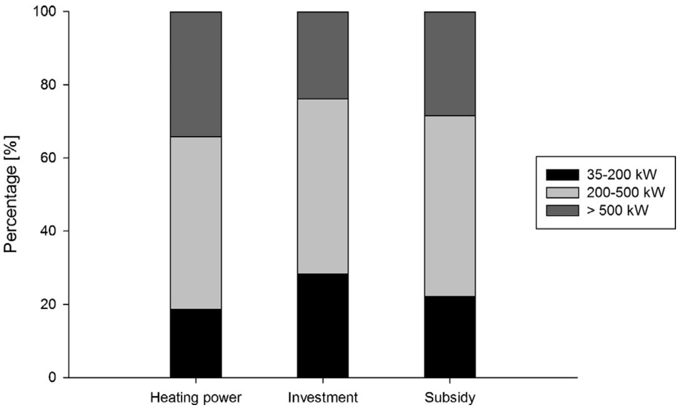

Fig. 2. Percentages of heating power capacity, investment cost and subsidy for different ranges of power of plants.

Table 6
Primary energy and emission savings.

Cases analyzed	Fossil primary energy TOE	CO_{2eq} emission t	NO_x emission t	SO_2 emission t
Diesel plants	470,263	1,443,611	1181	1969
Natural gas plants	397,615	924,694	208	8
Savings	72,648	520,481	973	1960
Relative savings	15.4%	36.0%	82.4%	99.6%

Table 7
Indicators related to effectiveness and cost/effectiveness with respect to subsidy.

	Range	Heating power MW	Primary energy saving TOE	CO_{2eq} emission saving t	NO_x emission saving t	SO_2 emission saving t
Effectiveness	35–200 kW	62.6	15,575	111,471	208.3	419.6
	200–500 kW	157.8	36,507	261,907	489.9	987.0
	>500 kW	114.7	20,567	147,104	274.8	553.6
	Total	335.0	72,648	520,481	973.1	1960.2

	Range	Specific heating power subsidy €/kW	Specific primary energy saving cost €/TOE	Specific CO_{2eq} emission saving cost €/t	Specific NO_x emission saving cost €/t	Specific SO_2 emission saving cost €/t
Cost-effectiveness with respect to subsidy	35–200 kW	20.0	80.1	11.2	5986	2972
	200–500 kW	17.7	76.3	10.6	5686	2822
	>500 kW	14.0	78.1	10.9	5844	2901
	Total	16.8	77.6	10.8	5795	2876

respect to baseline. The emission savings amount to 518,917 t of CO_{2eq}, 959 t of $NO_{x\ and\ 1}$, and 1960 t of SO_2 corresponding respectively to a reduction of 36%, 82% and nearly 100%, as highlighted in Table 6 and Fig. 3.

After considering the energy and environmental performance in absolute terms, the same indicators were analyzed in relative terms, with respect to the size of the plants and the subsidy, as shown in Table 7.

It is possible to argue from Table 7 data that the specific investment cost per unit of power varies significantly with the size of the heating system, showing an economy of scale in the interventions. With respect to energy efficiency titles (white certificates, TEE) for Italy, the market value is around 100 €/TOE (GME, 2012) while the cost for the average public administration in the program was 77.6 €/TOE. The specific costs for the public administration of CO_{2eq}, NO_x and SO_2 avoided emissions are respectively 10.8 €/t, 5838.5 €/t and 2876.2 €/t. The cost of avoided CO_{2eq} emission is in the range of the market value of the EU emission trading system (ETS) (Ellerman & Joskow, 2008; EU ETS, 2014). However, since we know that the EU ETS is governed by a market mechanism that doesn't reflect the actual characteristics of the reference energy and environmental system, a more appropriate approach would be to consider the value of efficiency titles (about 100 €/TOE, as introduced before) and the average $t_{CO_{2eq}}/TOE$ ratio at the national level over the time frame of the analysis, equal to $2.42 t_{CO_{2eq}}/TOE$ (IEA, 2012), to obtain a more realistic value with respect to the actual conditions of the reference energy system. In this case the reference value obtained would be around 41 €/$t_{CO_{2eq}}$, confirming the inherent good result obtained by this efficiency measure. Another possible approach would be considering the Social Cost of Carbon (SCC) (Johnson, Yeh, & Hope, 2013), but this type of calculation requires a more detailed approach and cannot be applied in this specific research.

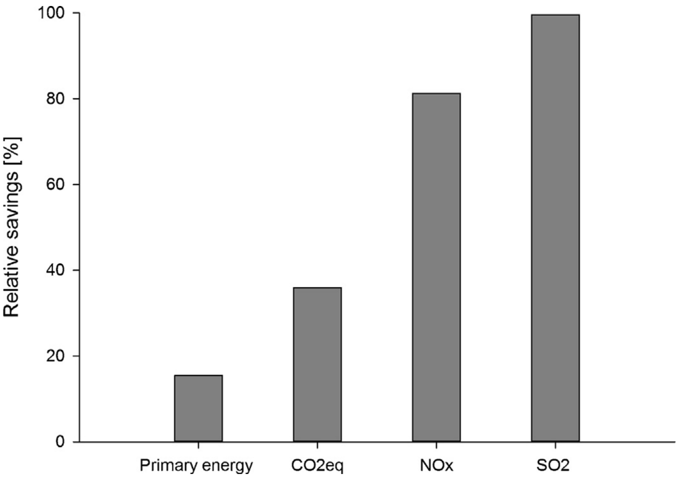

Fig. 3. Relative savings of primary energy, CO_{2eq}, NO_x and SO_2 emissions.

The average amount of subsidy given is equal to approximately 13.80% of the initial investment budget and the values for the different ranges of power are reported in Table 8.

The proportional increase shows how a slightly lower incentive on the medium and large plants would be fairer. On the other hand, we can analyze the support program from the end-user perspective, taking into account the previously introduced economic indicators *NPV* and *DPB* reported in Table 9 (with and without subsidy).

The average *DPB* shows the difference in terms of competitiveness among small, medium and large plants, highlighting the economy of scale and the maturity of the technology from the market point of view, with a limited difference in presence or absence

Table 8
Initial investment budget, subsidy provided and subsidy/investment ratio.

Range	Investment cost €	Subsidy €	Subsidy/ investment %
35–200 kW	11,544,190	1,246,940	10.8
200–500 kW	19,565,969	2,785,560	14.2
>500 kW	9,740,687	1,606,055	16.5
Total	40,850,846	5,638,555	13.8

Table 9
Performance indicators for the average cases.

Range	**Power installed** kW	Primary energy saving TOE	**Specific investment cost (with/without subsidy)** €/kW	NPV **(with/without subsidy)** €	**DPB (with/without subsidy)** y	Maximum DPB **(without subsidy** y
35–200 kW	135.7	31.9	164.6/184.5	67,966/65,261	3.8/4.3	14
200–500 kW	308.2	67.6	106.3/124.0	164,491/159,050	2.6/3.1	12
>500 kW	902.9	152.7	70.9/84.9	382,524/369,878	2.4/2.8	10

of subsidy. The data in Table 9 show also how the not symmetrical distribution of the results in terms of DPB. In fact, the data were not uniformly distributed, with a large predominance of cases with value near the average. There exists, in any case, a very limited number of cases in which the investment has a long recovery time, mainly due to necessity of radical interventions. Finally, we compare in Fig. 4 what would have been the result with three alternative strategies of efficiency support, the use of efficiency titles (TEE 100 €/TOE) and the use of two possible CO_{2eq} cost (10 and $40\,€/t_{CO_{2eq}}$) of the reference energy system.

In this case, we found that energy efficiency titles provoke only a moderate change, and that the minimum CO_{2eq} cost obtains the same results as efficiency titles. Finally, we observed that a CO_{2eq} cost more representative of the actual reference energy system ($40\,€/t_{CO_{2eq}}$) determines a result very similar to the one achieved by the support program studied, evidencing the fact that a fair payment of the carbon avoided emission (i.e. considering the real characteristics of the energy and environmental reference system) would have the same impact, but potentially on a much broader scale. We selected to develop a unified graphical representation of the following list of parameters, reported previously in Tables 5–9, for each range of power:

1. capacity installed;
2. investment cost;
3. subsidy;
4. primary energy saving;
5. CO_{2eq} emission saving;

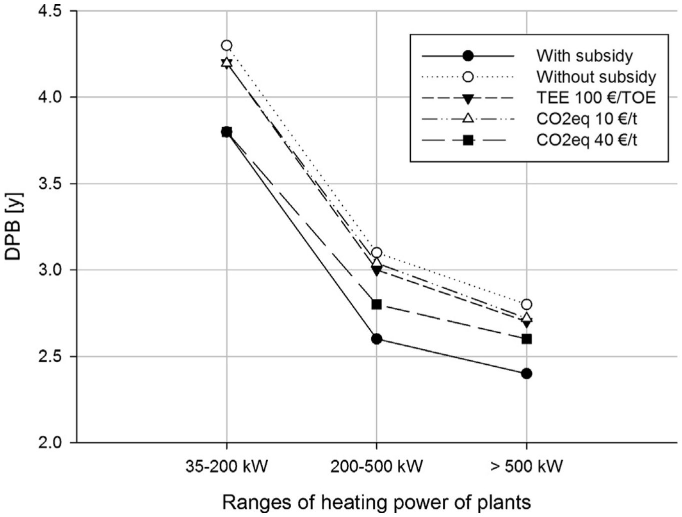

Fig. 4. Average discounted payback for the different ranges of heating power of plants and different support options.

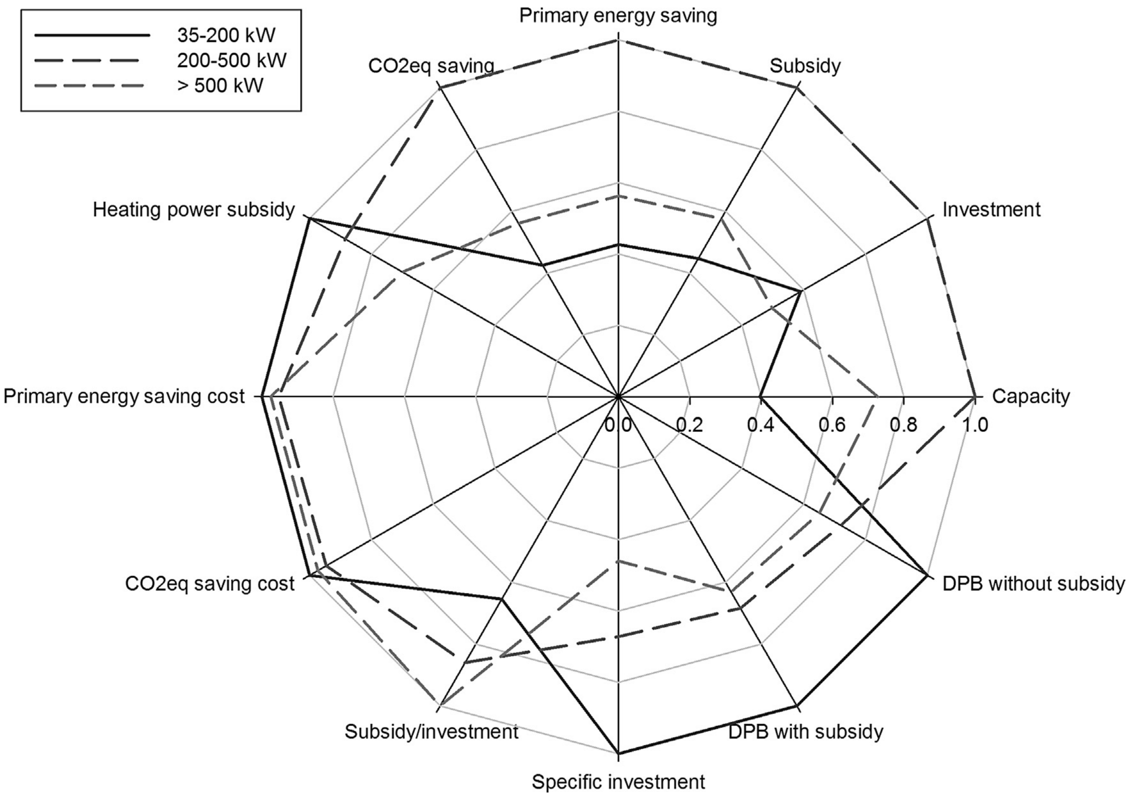

Fig. 5. Multi-criteria visualization of the outcomes of the efficiency program.

6. specific heating power subsidy;
7. specific primary energy saving cost;
8. specific CO_{2eq} emission saving cost;
9. subsidy/investment;
10. specific investment cost;
11. DPB with subsidy;
12. DPB without subsidy.

In order to present them in a synthetic way (multi-criteria visualization to integrate multiple dimensions and perspectives in the evaluation of the outcomes of the program), we normalized them with respect to the maximum value of each parameter to obtain relative weights (Ishizaka & Nemery, 2013), using the following formula:

$$w_i = \frac{v_i}{v_{i,\max}} \tag{6}$$

After that, we represented them in Fig. 5. In this way, it is possible to visually compare the results of the different ranges of power with respect to the different criteria selected. What emerges clearly is the importance of the medium size plants, both in absolute terms (total primary energy and emission savings) and in relative terms (DPB). This range of size appears to be a very interesting target, in particular for the introduction of natural gas fuelled DG technologies (Carpaneto et al., 2011a, 2011b). Finally, it is worth noticing that this analysis approach can be extended to the overall framework program, for example by means of multi-criteria scoring and analytic hierarchy process (AHP) techniques (Ishizaka & Nemery, 2013), and that, given the possible rapid evolution of the reference scenario in terms of costs for technologies, efficiency titles and emissions, the results should be always approached with a critical view, considering the sensitivity to the different assumptions.

5. Conclusions

In recent years, energy policies have become increasingly more ambitious under the pressure of energy market evolution and governmental initiatives for the support of energy efficiency and renewable energy technologies. On the one hand, policies result in costs for the public administration; on the other hand, local scale programs represent an important element for the transition towards a more sustainable energy paradigm. Local programs can be effectively employed as a mean to accelerate this process if they are correctly designed.

The research presented involved the analysis and monitoring of the interventions subsidized by Lombardy region within the “Framework Program Agreement in the field of Environment and Energy”, focusing on the replacement of diesel oil boilers with high efficiency natural gas boilers, mostly condensing ones.

The final result, in terms of primary energy saving, amounts to approximately 72,648 TOE in 15 years with a 15% reduction with respect to the baseline constituted by diesel boilers. In the same timeframe, emission savings amount to 518,917 t of CO_{2eq}, 959 t of NO_x and 1960 t of SO_2 corresponding respectively to a reduction of around 36%, 82% and nearly 100% respectively.

Starting from the consideration that the market value of energy efficiency titles is about 100 €/TOE and that the average cost for the public administration was equal to 77 €/TOE, condensing natural gas boiler has proven to be a cost-effective technology. With respect to the carbon dioxide emission cost, the average value found is 10.8 €/t, substantially in the range of the market value of the EU emission trading system.

If we consider the years of publication of the calls, 2004 and 2005, we can state that condensing boiler was already a mature technology, widely available on the market and competitive from the techno-economic point of view. This assertion is confirmed by the data collected; in fact, the discounted pay-back time for the different plants, variable between 4.3 and 2.8 years, indicates that the investment is profitable even without subsidies that change the result only by a few months.

At present, the newly installed heating systems represent approximately the 20% of the total market at the regional level, while the existing ones amount to the 80%. Although in some cases subsidies might not be as cost/effective as expected, or appropriate when applied to a mature technology, they can nonetheless play an import role to stimulate the phase-out process of less efficient technologies and, more in general, to address an evolution process that the market itself cannot handle rapidly, due to the presence of different types of barriers, not exclusively on the economic side. It is undisputable that energy efficiency has to be addressed with policies, because “business as usual” strategies are simply not enough with respect to ambitious energy and environmental goals, such as the ones set today at global scale. As a matter of fact, these goals should be reached with constrained economic resources and in a relatively short time. In this sense, the scope of the research was not merely the identification of the global outcomes of the program, but also the development of a methodology suitable for further applications, with a general frame for analysis, as outlined in Section 3 and more specifically in Table 2 that reports the fundamental thematic areas of the analysis and the relative indicators, which can be dependent in part from the specific technology.

The rapid evolution of efficiency standards that is taking place at the European level pushes forward for more pervasive solutions, increasing the inherent complexity of the transition process itself. The focus of future policies should be placed not merely on single technologies, but rather on integrated solutions at building and neighbourhood scale (determining different boundaries for the analysis and several technologies to be considered), tailored on the specificity of the end-user and able to push intelligence to the edges of the energy infrastructures (e.g. smart automation, distributed generation, etc.). The necessity to establish restrictive performance requirements on heterogeneous technological systems claims for the use of intensive data collection, analysis and transparent multi-criteria decision making methodologies. These concepts are today partially envisioned in present legislation at the EU level, for example in the methodology for cost-optimal analysis of buildings, introduced in the EPBD recast framework. Despite the potential efforts required to apply this approach, we believe that its coherent application can open up new perspectives in terms of savings (energy and emissions) and economic competitiveness.

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