Energy and Buildings

Optimizing the distribution of Italian building energy retrofit incentives with Linear Programming

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abstract

The goal of the research is to propose an optimization-based methodology for the evaluation of retrofit incentives, using as a benchmark the wide data collection reported by the ENEA Italian Agency since 2007. To determine the best mix of energy retrofit measures for different areas of Italy, two Linear Programming models are proposed. The first model maximizes energy savings and the second one minimizes retrofit costs. The results show a 17% reduction in the average cost for each MWh of saved energy. More importantly, the methodology can help decision-makers appreciate how energy efficiency incentives have been used so far and how effective they could be. Furthermore, the methodology can be used for setting future incentive distribution plans.

1. Introduction

“Buildings are at the centre of our social and economic activity. Not only do we spend most of our lives in buildings, we also spend most of our money on buildings. The built environment is not only the largest industrial sector in economic terms, it is also the largest in terms of resource flow”[1].

Nearly 76% of Italian dwellings were built before the first Italian law on building energy performance had been issued (Law N.373/1976). The old age of the existing residential building stock (in Italy, 49% of dwellings are more than 50 years old [2,3], whereas in Europe, this percentage is around 35%) typically goes with poor energy building performances.

Moreover, even though in Italy the first building legislation on energy performance was adopted in 1977 and several updates have been implemented, energy consumption levels in the residential sector have not successfully decreased. After the EPBD 2002/91 regulation was issued, a decrease ranging between 0.8% and 0.4% was registered in the growth trend for energy consumption. However, the low growth of new high-performance dwellings is not enough to invert the energy consumption trend. The implementation of effective retrofit solutions for the widely existent building stock is therefore necessary.

Since the European policy aims to significantly decarbonize the continent’s economy by targeting a cut of 80–95% below 1990 levels by 2050, the building sector undoubtedly plays a key role [4]. Moreover, any strategy to tackle the challenge in this field will clearly require both a significant amount of financial investments and long-term political commitments [5,6].

Nonetheless, it is very important to find out how to foster and encourage energy efficiency improvements and energy-saving measures in private dwellings, in order to achieve the advantages of reducing energy consumption in the private sector, as well as increasing investments and favouring the creation of additional cash flows. This combination of multiple benefits therefore makes the building sector a crucial field for policy-makers at the European and national levels.

The development of sustainable solutions for the refurbishment of existing buildings requires major innovations in retrofitting strategies and cost-effective and fruitful financing instruments [7–11]. In order to cope with the main European goals and energy saving targets, the Italian government has recently established a system of

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financial incentives: they allow a tax deduction for a wide range of energy efficient retrofit investments, sustained both by private citizens and by companies. The deductions essentially consist of subsidies for energy-saving refurbishments in the household sector (a.k.a., “Energy Efficiency 55%”) financed by the Ministry of Economic Development. They concern opaque vertical and horizontal surfaces insulation, window replacement, solar panel installation, and thermal plants replacement carried out in existing buildings, as long as they are duly proved, certified, and respectful of specific technical requirements (such as transmittance limits, thermal plants efficiency, etc.).

However, these subsidies are granted without congruous and logical distribution criteria, overlooking their effective and final profitability, regardless of a fair evaluation in terms of their real cost-effectiveness. Hence, a far-sighted incentives distribution policy would be beneficial. Despite this shortcoming, a rather worthy initiative and investigation venture has been recently implemented by the ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development): it collected all the relevant data and information on the previous subsidies, and created a wide reports portfolio. In particular, these reports are able to inform the authorities about costs, energy savings, and the occurrences of retrofits in all Italian regions.

This study aims to analyse the ENEA reports to quantify the cost-effectiveness of several building retrofit actions in different geographic areas. Next, the analysis of ENEA data is used to propose two Linear Programming [LP] models in order to determine which retrofit measures maximize energy savings and minimize retrofit costs in these geographic areas. The national scale of these models enforces the idea that buildings should no longer be renovated individually, but as a part of a global energy system where their interaction with the environment should be predicted and properly evaluated, while also taking into account the relationship with inhabitants and relevant stakeholders [12–17]. Finally, this study compares the outcomes of the LP models to the data derived from the ENEA reports.

2. Literature review

There are many obstacles to the spreading of good practices concerning the use of retrofit incentives. One of the main problems is the cost-effectiveness of home energy retrofits [18], which is rarely taken into account in national policy programs. In particular, the literature review highlights some critical issues:

Public subsidies are necessary to reduce payback time and increase economic benefits for investors [7,18].

Uncertainties about future energy prices make the economic feasibility analysis of a given work really difficult [12,19].

The value chain of the building sector is quite complex and involves a wide range of stakeholders, such as investors, building planners, property traders, equipment manufacturers, entrepreneurs, and last but not least, end-users. Hence, despite the incentives for taking action towards energy efficiency, all stakeholders face several obstacles. Such barriers too often prevail, resulting in too little action and a limited impact so that only a small part of the latent potential can be effectively carried out [20].

A key requirement for the analysis of retrofit incentives is the availability of reference data. Many reports and surveys were published, at both the European and international levels, taking a closer look at how financial instruments are currently implemented in Europe and providing some evidence of their effectiveness [21–29]. In particular, they underline a great variety of financial instruments available throughout the EU to support the improvement of a building’s energy performance [30–35]. However, despite their undoubted relevance, none of them have analysed in detail the respective implications at a “single-nation-level”. As a matter of fact, this particular topic is not thoroughly discussed, neither in the scientific literature, nor in specific technical guidelines: the example offered by the ENEA Reports [36,37] could represent, at a national level, a very important instrument for addressing the challenge of renovating the existing building stock, while also keeping pace with the ambitious aims of both the Italian nation and the European Union.

Several studies have already been carried out in the Linear Programming and optimization field. Some mixed integer programming techniques have been developed for building retrofits and energy-saving refurbishments in the residential sector in addition to the implementation of renewable and sustainable energy. Single and multi-objective optimization techniques have been proposed for short-term energy planning that consider multiple uncertainties and unpredictable parameters [38–41]. Furthermore, specific algorithms and mathematical techniques have been implemented to optimize insulation measures on existing buildings, as well as evaluate economic optimal retrofit investment options and solutions for energy savings [42,43]. LP has already been adopted to assess and sustain household energy conservation and heating systems. It has also been used for the evaluation of building energy systems to obtain an efficient allocation of the required budget [44–46]. Nevertheless, none of the previous studies attempted to evaluate energy retrofit solutions within an integrated optimization process.

This paper aims to cover the gap of adopting LP to assess economic and energy building retrofit policy implications under a strategic perspective. In the following section, some details are added about LP, although ad hoc books are required for a complete overview [47].

2.1. On Linear Programming

LP is concerned with the minimization or maximization of a linear function while satisfying a set of linear equality and/or inequality constraints. An LP model can be formulated as:

$$\min \sum_{j=1}^{n} c_j x_j \qquad (1)$$

s.t.

$$\sum_{j=1}^{n} a_{ij} x_j = b_i \qquad i=1,\ldots\ldots m, \qquad (2)$$

$$x_j \geq 0 \qquad j=1,\ldots\ldots,n \qquad (3)$$

where, Eq. (1) is the objective function to be minimized. The coefficients $c_1,\ldots.,c_n$ are known coefficient costs and $x_1,\ldots.,x_n$ are the decision variables to be determined. Equation (2) is the ith constraint, which is made up by the technological coefficients a_{ij}, and b_i is the ith requirement to be satisfied by decision variables.

Inequalities (3) are the non-negativity constraints. A set of values of the variables $x_1,..,x_n$ satisfying all the constraints is called a feasible point or a feasible solution. The set of all such points constitutes the feasible region or the feasible space. According to this terminology, the LP problem can be stated as follows: among all feasible solutions, find one that minimizes (or maximizes) the objective function.

3. Methodology

In the methodology, the data provided in yearly ENEA reports are analysed and processed. In addition, two LP models using the parameters determined from the ENEA data are presented. All the LP problem instances are solved to the optimum by a freeware release of the solver Lindo [48].

Table1
Technicalrequirementsforgettingenergyretrofitsubsidiesdependingon Italianclimaticzoning.

Climatic zone D.D. H.	Opaque vertical surfaces (U-value range) [W/m^2 K]	Opaque horizontal surfaces (U-value range) [W/m^2 K]		Windows (U-value range) [W/m^2 K]	Thermal plants replacement	Solar panels
		ROOFS	FLOORS			
A(D.D.H<600)	0.72–0.54	0.42–0.32	0.74–0.60	5.0–3.7	Respectfulofwhatprescribed inArt.9ofthe Ministerial Decreeissuedon19/02/97.The condensingboilerefficiencyat 100%loadmustfulfilthe respectivelimitsprescribedby lawandanalogous limitsare imposedforCOPofheatpumps (andEer,incoolingmode).	Dulycertifiedand respectfulofwhatis prescribedinArt.8of the MinisterialDecree issuedon19/02/97. Theymustcomply withEUstandardsUNI EN12975andUNIEN 12976.
B(600<D.D.H<900)	0.54–0.41	0.42–0.32	0.55–0.46	3.6–2.4		
C(900<D.D.H<1400)	0.46–0.34	0.42–0.32	0.49–0.40	3.0–2.1		
D(1400<D.D.H<2100)	0.40–0.29	0.35–0.26	0.41–0.34	2.8–2.0		
E(2100<D.D.H<3000)	0.37–0.27	0.32–0.24	0.38–0.30	2.5–1.8		
F(D.D.H>3000)	0.35–0.26	0.31–0.23	0.36–0.28	2.2–1.6		

3.1.AnalysisoftheENEAreports

Thisresearchisbasedontheannualreportsprovidedbythe ENEAsince2007. Thetypesofretrofitsareorganizedasfollows:

- Opaqueverticalsurfaces;
- opaquehorizontalsurfaces;
- windowreplacements;
- thermalplantsinstallation;
- solarpanelinstallation.

These retrofits are required to meet the technical requirements, as shown in Table 1, according to the Italian climatic zoning in terms of Average Heating DegreeDays,whicharedenotedbyD.D.H.

No additional technical features are imposed on energy-saving refurbishmentstoobtainsubsidies.Engineersorarchitects,whoare inchargeof designing retrofit measures, also state the compliance of each intervention with the imposed limits and record it for ENEA reports. As there is no disaggregated data on costs and savings, this study takes the following figures from the ENEA reports:

- Thetotalnumberoftheabove-listedtypesofretrofitregistered ineachItalian region;
- theaveragecost[Đ]assessedforanytypeofretrofitineach region;
- theaverageenergysavings[MWhperyear]foranytypeofretrofit ineach region.

Thelastparametersarebasedonthefollowingassumptions aboutlifetimes: 50yearsforbothverticalandhorizontalsurfacesinsulation(i.e.,walls,floors,and roofs), 30 years for windows replacement, and 25 years for both solar thermal panelinstallation andheatingplantsreplacement[49–52].

Owing to the relevant differences in the number of recorded retrofits among regional data, regions are clustered into macroareas according to their geographical proximity and socioeconomic similarities. The macro-areas are showninFig.1.

Next,theweightedaveragecostandtheweightedaverage energysavingsare computed for each retrofit and each macro-area, using as weights the number of retrofitsrecordedintheregions ofthatmacro-area.Finally,theweightedaverage costandthe recordednumberofretrofitsareusedtocomputethebudgetfor each macro-areaandeachretrofit.

InSection3.2,suchapreprocessingelaborationismathematicallydescribed.

3.2.Notation

LetJbethesetofthedifferenttypesofbuildingretrofit.Itis initializedwiththe followingfiveelements,eachonedenotedby theindexj:

OO	opaquehorizontalsurfacesinsulation(floorsandroofs);
OV	opaqueverticalsurfacesinsulation(walls);
IN	replacementofwindowswithlowtransmittanceones;
ST	installationofsolarthermalcollectors;
CI	replacementofboilerswithcondensingonesorwith high-efficiencyheatpumps.

LetIbethesetofzones,whichismadeupoffiveelementscorrespondingtothefive main Italian geographical macro-areas. It is initialized with the following five elements,eachonedenotedby theindexi:

NW	northwestItalianmacro-area(Piemonte,Valled’Aosta, Lombardia,Liguria);
NE	northeast Italian macro-area (Trentino-Alto Adige, Veneto,Friuli-VeneziaGiulia,Emilia-Romagna);
CE	centralItalianmacro-area(Toscana,Umbria,Marche, Lazio);
ME	southernItalianmacro-area(Abruzzo,Molise,Campania, Puglia,Basilicata,Calabria);
IS	islandsItalianmacro-area(SiciliaandSardegna).

Inaddition:

- r is the region index in the ith Italian macro-area and Ri is the set of regions in the macro-areaI.
- c_{rj} istheaveragecostoftheretrofitactivityj∈Jintherthregion ofthemacro-areai∈I.
- s_{rj} istheaveragesavingsoftheretrofitactivityj∈Jintherth regionofthemacro-area i∈I.
- n_{rj} isthenumberofretrofitsoftypej∈JregisteredbytheENEA intherthregionofa macro-area.
- $N_i$istheoverallnumberofenergybuildingretrofitsregisteredby theENEAinthe macro-areai∈I.

Fig. 1. Italian macro-areas.

- a_{ij} is the weighted average cost of a retrofit $j \in J$ in the macro-area $i \in I$. It is calculated as follows:

$$a_{ij} = \sum_{r \in R_i} \frac{n_{rj} c_{rj}}{N_i} \quad \forall i \in I, \forall j \in J \quad (1)$$

- s_{ij} is the weighted average energy savings produced by one retrofit activity $j \in J$ in the macro-area $i \in I$. It is calculated as follows:

$$s_{ij} = \sum_{r \in R_i}^{n} \frac{n_{rj} s_{rj}}{N_i} \quad \forall i \in I, \forall j \in J \quad (2)$$

- b_i represents the budget used in any Italian macro-area $i \in I$, as gathered from the ENEA; it is computed as the sum (considering all the retrofit actions) of the product between the weighted average cost of retrofit $j \in J$ in the macro-area $i \in I$ and the recorded occurrences n_{ij} of retrofit activity $j \in J$ in the macro-area $i \in I$:

$$b_i = \sum_{j \in J} a_{ij} n_{ij} \quad \forall i \in I \quad (3)$$

- b_j represents the budget used for any retrofit type $j \in J$, as derived from the ENEA; it is computed as the sum (considering all the geographic zones) of the product between the weighted average cost of retrofit $j \in J$ in the macro-area $i \in I$ and the recorded occurrences n_{ij} of retrofit activity $j \in J$ in the macro-area $i \in I$:

$$b_j = \sum_{i \in I} a_{ij} n_{ij} \quad \forall j \in J \quad (4)$$

3.3. The first LP model

The first LP model aims to determine the number of retrofits in each macro-area in order to maximize energy savings without exceeding the budget for any macro-area or retrofit type. This model makes use of the notation presented in Section 3.2. Decision variables are denoted by x_{ij}, which represents the number of retrofit actions $j \in J$ to be performed in the macro-area $i \in I$. Each decision variable x_{ij} must have a value in the range delimited by the lower bound l_{ij} and the upper bound u_{ij}, which must be set to avoid outliers.

The first mathematical model is formulated as follows:

$$\text{Max} \sum_{i \in I} \sum_{j \in J} s_{ij} x_{ij} \quad (5)$$

s.t.

$$\sum_{j \in J} a_{ij} x_{ij} \le b_i \quad \forall i \in I \quad (6)$$

$$\sum_{i \in I} a_{ij} x_{ij} \le b_j \quad \forall j \in J \quad (7)$$

$$l_{ij} \le x_{ij} \le u_{ij} \quad \forall i \in I, \forall j \in J \quad (8)$$

In (5), energy savings are maximized. Constraints (6) and (7) impose that the total refurbishments cost to be supported is not higher than the annual expenses reported in the ENEA reports for any macro-area and for any type of retrofit, respectively. Constraint (8) enforces each decision variable to be in the range between the lower and upper bounds.

3.4. The second LP model

The second LP model aims to minimize retrofit costs while enforcing energy savings larger than those obtained in the first LP model. The second LP model makes use of the notation introduced in Section 3.2 and Section 3.3. In addition:

- c_{ij} is the average cost required for performing the retrofit $j \in J$ in the macro-area $i \in I$. It is calculated as:

$$c_{ij} = \sum_{r \in R_i} \frac{n_{rj} c_{rj}}{x_{ij}} \quad \forall i \in I, \forall j \in J \quad (9)$$

  where, n_{rj} is the number of retrofits of type j registered by the ENEA in the rth region of a macro-area and c_{rj} is the cost of the retrofit of type j registered by the ENEA in the rth region of a macro-area;
- y_{ij} are the decision variables of the new LP model and are defined as the number of retrofits of type $j \in J$ to be performed in the macro-area $i \in I$.

The minimization model is formulated as follows:

$$\text{Min} \sum_{i \in I} \sum_{j \in J} c_{ij} y_{ij} \quad (10)$$

s.t.

$$\sum_{j \in J} s_{ij} y_{ij} \ge \sum_{j \in J} s_{ij} x_{ij} \quad \forall i \in I \quad (11)$$

$$\sum_{i \in I} s_{ij} y_{ij} \ge \sum_{i \in I} s_{ij} x_{ij} \quad \forall j \in J \quad (12)$$

$$l_{ij} \le y_{ij} \le u_{ij} \quad \forall i \in I, \forall j \in J \quad (13)$$

It is worth noting that the values of x_{ij} in (11) and (12) are taken from the solution of the first LP model. These constraints enforce the energy savings determined in the first LP model as minimum requirements for the second LP model. Constraint (13) provides the lower and upper bounds for the values of the decision variables.

3.5. Optimization and statistical dispersion analysis

For each ENEA report from 2007 to 2011, one instance of the first LP model and one instance of the second LP model are generated and then solved through Lindo [48]. More importantly, its optimization engine is an exact algorithm—the Revised Simplex Method [47] thus, whenever it converges, it is guaranteed that no better feasible solution exists that could improve upon the one obtained by this solver.

The solution of the second LP model shows a retrofit distribution more concentrated than that registered by the ENEA. In order to quantify the statistical dispersion in the frequency of retrofits, several indicators could be used. As we are interested in a dimensionless quantification of inequality in the retrofit distribution, a suitable measure of statistical dispersion is the Gini index, which is adopted in this study [53]. The value zero of the Gini coefficient expresses perfect equality, where all retrofits have the same frequency. The value one (or 100%) of the Gini coefficient expresses maximal inequality among retrofit occurrences (for example, only one retrofit type is performed).

This index provides a worthwhile measure for the statistical dispersion of a generic distribution of variables.

The Gini index is computed as:

$$G(S) = 1 - \frac{2}{25-1}\left(25 - \frac{\sum_{k=1}^{25} k y_k}{\sum_{k=1}^{25} y_k}\right) \qquad (14)$$

where, $y_1, \ldots, y_{25}$ is the vector of decision variables obtained from the solution of the second LP model, provided that these variables are arranged in a descending order.

Table 2
Outcomes on the time span 2007–2011.

	Energy savings [MWh]	Retrofit costs [D]	Gini index
Year 2007			
Registered by ENEA	14,220,045	840,163,056	0.621
Outcome of the first LP model	16,151,175	840,195,277	0.804
Outcome of the second LP model	16,151,180	820,298,900	0.832
Year 2008			
Registered by ENEA	41,615,338	2,225,404,392	0.646
Outcome of the first LP model	51,281,330	2,225,591,799	0.827
Outcome of the second LP model	51,281,930	2,131,751,000	0.824
Year 2009			
Registered by ENEA	44,300,000	2,563,271,161	0.634
Outcome of the first LP model	50,562,780	2,563,258,868	0.784
Outcome of the second LP model	52,124,140	2,531,344,000	0.804
Year 2010			
Registered by ENEA	61,675,990	4,607,733,288	0.698
Outcome of the first LP model	73,755,680	4,607,688,162	0.829
Outcome of the second LP model	82,908,163	4,934,292,000	0.898
Year 2011			
Registered by ENEA	43,189,571	3,308,708,525	0.710
Outcome of the first LP model	50,066,410	3,308,683,136	0.822
Outcome of the second LP model	50,310,902	3,246,384,000	0.858

4. Experimentation and numerical results

Significant energy savings can be registered by adopting the proposed optimization methodology. Table 2 reports for each year the average energy savings, the average retrofit costs, and the Gini index according to ENEA data, the optimal value of (5) from the first LP model, and the optimal value of (10) from the second LP model. This table shows that significant energy savings are obtained after the first LP model is solved and additional savings are often obtained by the second LP model.

More precisely, the energy-saving increase was 13.50% in 2007, 23.22% in 2008, 17.66% in 2009, 34.43% in 2010, and 16.49% in 2011. It is worth noting that, except for 2010, the retrofit costs are lower than those recorded in the ENEA reports. Figs. 2 and 3 show the improvements obtained by the first LP model and by the second one, respectively.

Table 2 also shows that the optimization results in higher values of the Gini index. Despite the more balanced distribution of retrofits in the ENEA reports, they result in low energy savings with respect to the outcomes obtained by the LP models. In 2007, the year’s more balanced distribution cost around 2,000,000 MW h saved (16,151,180–14,220,045).

Table 3 shows the number of retrofits recorded in the ENEA reports and determined by the second LP model in order to point out where the most relevant differences are clustered. According to the ENEA data, IN retrofits (i.e., replacement of windows with low transmittance ones) are quite popular in the north. Despite the very similar climate conditions between the northwest and northeast, the proposed methodology recommends a larger use of CI retrofits (i.e., replacement of boilers with condensing ones or with high-efficiency heat pumps) in the northwest. IN retrofits are quite common even in the central macro-area, but the methodology advises a larger use of ST (i.e., installation of solar thermal collectors) and CI retrofits. Finally, a superior usage of ST retrofits is recommended in the south and in the islands, which exhibit similar climate conditions.

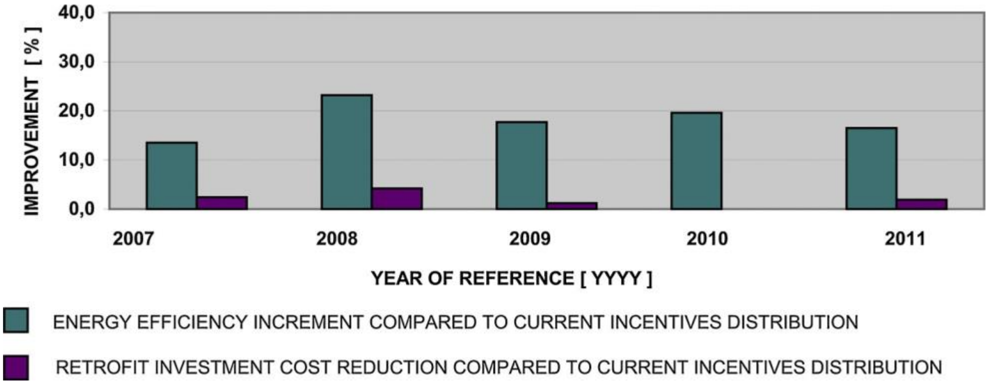

Fig. 2. Optimal solutions of the first LP model versus ENEA data.

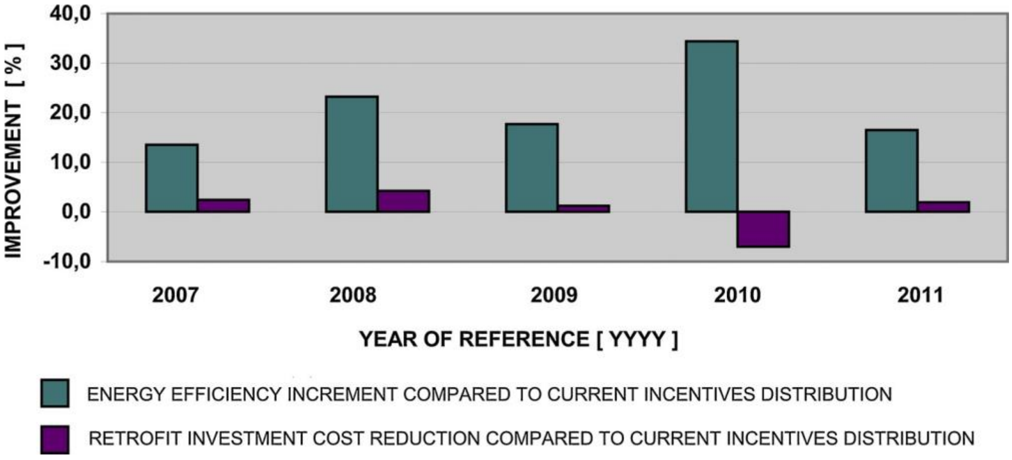

Fig. 3. Optimal solutions of the second LP model versus ENEA data.

Table 3
Number of retrofits recorded in the ENEA reports [ENEA] and determined by the second LP model [OPT].

Retrofits	North-west		North-east		Centre		South		Islands	
	ENEA	OPT	ENEA	OPT	ENEA	OPT	ENEA	OPT	ENEA	OPT
2007 OO										
	413	156	472	159	280	2393	119	137	52	389
OV	674	150	932	1641	379	150	188	137	53	114
IN	13,868	4050	10,263	27,650	5410	118	2863	93	935	88
ST	3341	137	8899	142	3180	4193	978	6216	2661	4264
CI	9620	21,640	9564	154	5756	153	2068	594	563	136
2008 OO										
	2339	4088	2518	1286	916	154	341	144	139	135
OV	1221	158	1690	2980	285	150	227	147	62	135
IN	42,915	21,309	28,484	71,216	16,972	117	9731	85	3306	89
ST	6691	153	16,525	152	6484	21,358	2480	16,903	4417	9411
CI	21,563	44,215	21,999	153	12,543	6030	4124	2547	1487	833
2009 OO										
	4331	7894	3440	919	1481	152	407	146	179	137
OV	2133	153	2283	4093	438	146	385	1891	138	127
IN	48,735	32473	32,777	78,070	18,741	114	10,632	95	3921	85
ST	9383	148	15,771	148	5664	17,032	2079	19,486	3042	9930
CI	25120	38494	23800	149	13,209	25,479	5983	147	2650	1240
2010 OO										
	2338	5982	2555	0	880	0	316	0	145	0
OV	1570	14,608	2067	0	493	0	347	0	113	0
IN	94,503	0	62,986	201,001	36,208	3	20,058	2	7654	0
ST	14,527	0	19,542	0	7494	0	3088	38,538	3060	28,843
CI	48,079	84,651	43,890	0	20,232	42,494	9429	0	4053	0
2011 OO										
	2107	541	1957	3517	666	251	271	1449	117	141
OV	1399	174	1665	171	418	3966	277	161	114	135
IN	71,241	58,451	48,906	92,091	26,007	124	14,110	113	5402	100
ST	8761	165	12,683	167	4339	6740	1947	22,282	1841	9842
CI	29,878	62,776	26,885	156	11,665	148	5677	147	2371	4256

Finally, sometimes infeasibility issues need to be addressed. For example, in the instance of 2010, no feasible solution was found for the first LP model due to the initial values of restrictions' entries in (6) and (7). Although the debugging tools of the optimization solver provide details on the possible ways to restore feasibility, their selection is left to the decision-makers. In this case, the lower and upper bounds on the solar panel retrofits have been removed, obtaining an energy saving level still larger than that registered by the ENEA (73,755,680 MW h > 61,675,990 MW h). Furthermore, it would result in a global investment cost amounting to D 4,607,688,162, which is slightly lower than the one reported by the ENEA (D 4,607,733,288).

5. Conclusion

This study has proposed two LP models to improve the distribution of energy building incentives. They are tested on an Italian case study, which is quite interesting, owing to the heterogeneity of the economic and climatic features of the nation's areas. The models lead to a significant reduction in the average cost for each MWh of energy saved: it amounts to D53/MWh versus the D64/MWh registered by the ENEA.

The results discussed in the research confirm the impact of the proposed methodology on this problem. More importantly, they provide clear proof of how powerful and strategic (if properly handled by policy makers) the proposed methodology is for investigating future incentive policies and energy-financial plans. For example, the method can be used to determine the ineffective retrofits in each area, limit their use whenever subsidies are requested, and switch the focus of users on taking more action. Moreover, the values of the Gini coefficient point out additional features of the optimized distribution of incentives: the lower values of this coefficient in the ENEA reports indicate a more varied use of retrofits in the entire Italian country, but they result in lower energy savings with respect to the proposed method.

Finally, while it is necessary to adopt a far-sighted policy intended to guarantee such incentives during a wider time span, significant care is needed in order to achieve more fruitful investments. Accurate data analysis will play a key role in providing incentive distributions that fit the needs of final users.

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