The heat-pump market in Italy: an in-depth economic study about the reasons for a still unexpressed potential

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Abstract

In this paper, the Italian heat-pump (HP) market is presented, with an overview over the past 10 years. In order to highlight market potential and barriers, a comparison is proposed between the economic performances of two different heating and domestic hot-water systems, air-to-water HPs and condensing boilers, based on several factors, such as energy costs, thermal loads, climatic conditions, HP-performance classes and some economic indicators such as the payback time and the interest rate. The results are presented in a parametric form, which may be profitably used for a comparative analysis with other European countries. The first part of the paper deals with the analysis of the current Italian HP market, to show its still unexpressed potential. The second part analyses the HP economic convenience with respect to the most commonly used heating technology, i.e. the gas boiler, under conditions typical of the Italian climate. The comparison is carried out in terms of two economic indicators: additional acceptable cost and net present value. The main results show that HP technology is economically competitive in most Italian climatic zones, with a strong dependence on the HP-performance class. In particular, if the best-performing class was adopted, economic gains would be guaranteed over the gas boiler, even with significant variations in the main influencing variables. Thus, the economic issue does not seem to be a limiting factor for HP technology diffusion, at least if the current incentives are maintained. Rather, some other barriers should be removed, such as the supply chain, the training of installation personnel and the final-user awareness.

Keywords: heat-pump market; cost analysis; building heating system comparison; renewable-energy sources

Introduction

Heat pumps (HPs) show many advantages over the competing technologies, which make them positively attractive. For instance, in terms of energy-use efficiency, the coefficient of performance (COP), which is defined as the ratio of the amount of energy injected into a heat sink, $Q_{in}$, to the amount of energy input, $L$, (electricity, fuel or primary energy), is always greater than unity. Indeed, the energy given to the final user is the sum of the energy input and the energy picked up from a thermal source.

The maximum theoretical COP that may be achieved by an HP is defined by the theoretical ‘Carnot-process’, where the efficiency is only related to the heat-source temperature ($T_0$) and to the heat-sink temperature ($T_1$), according to Equation (1):

$$\text{COP}_{\text{Carnot}} = \frac{Q_{in}}{L} = \frac{T_1}{T_1 - T_0} \tag{1}$$
In other words, the higher the temperatures difference between the heat source and the heat sink, the lower the performances of the HPs. The actual COP is always lower than the Carnot COP, due to many inefficiencies (compressor isentropic efficiency lower than 1, heat losses, finite temperature difference between source and evaporation temperature and between sink and condensation temperature, inlet compressor superheating, etc). On the other hand, HPs can guarantee to the user a thermal output greater than the primary energy input, unlike condensing boilers, which are the main competing technology in the residential-space-heating sector. Indeed, the latter, even if they are the most technologically advanced, are able to supply a thermal power lower than the primary energy they exploit (the primary energy being calculated on the fuel gross calorific value, GCV).

If the air-sourced HPs are considered, the gap between the supplied thermal energy and the primary energy exploited becomes increasingly smaller when the air temperature decreases; nevertheless, it remains greater than unity even in the worst climatic conditions.

To evaluate the seasonal performance of the HP, other indicators are used to take into account climate data input and effective electrical consumption of auxiliaries. In particular, the European normative EN 14825 [1] defines the seasonal coefficient of performance (SCOP_{net}) according to the following equation:

\[
\text{SCOP}_{\text{net}} = \frac{Q_{\text{HP}}}{E_{\text{HP,us}}}
\]  

In Equation (2), \(Q_{\text{HP}}\) is the sum of the heat supplied from the heat source via the HP and the heat supplied from the mechanical energy used to drive the HP; \(E_{\text{HP,us}}\) is the sum of the energy used to run the HP itself and the energy used to run the fan and/or pump for refrigerant circulation.

Due to the peculiar operating principle, the HP can transfer energy from renewable-energy sources (geothermal, aerothermal and hydrothermal) to the heat sink. Directive 2009/28/EC established the share of energy from renewable sources obtainable with an HP, considering that the energy used to drive HPs (typically electrical), also transferred to the sink, should therefore be deducted from the total renewable heat. Only HPs that yield an output significantly exceeding the primary energy needed to drive them should be taken into account.

The renewable-energy production from different HP technologies as required by Directive 2009/28/EC shall be calculated in accordance with the following formula [2]:

\[
E_{\text{RES}} = Q_{\text{usable}} \left( 1 - \frac{1}{\text{SPF}} \right)
\]

where

- \(Q_{\text{usable}}\) = the estimated total usable heat delivered by HPs, calculated as the product of the rated capacity for heating \(P_{\text{rated}}\) and the annual equivalent heat-pump hours \(H_{\text{eq}}\), expressed in GWh;
- SPF = the estimated average seasonal performance factor for those HPs. EC Decision 2013/114/EU [3] defines that the SPF should be according to the SCOP_{net}, as reported in EN 14825:2012.

Naming \(\eta\) the electrical power system efficiency, Directive 2009/28/EC states that only HPs with an SPF above 1.15/\(\eta\) will be considered as renewable-energy sources. If \(\eta\) is set at 45.5% [3], the minimum SPF of electrically driven HPs (SCOP_{net}) to be considered as renewable energy is 2.5.

Air-source HPs (ASHPs) on the market in recent years allowed Italy to achieve and overcome already in 2014 the share of energy from renewable sources planned for 2020 by PAN (National Action Plan for Renewable Energy) [4].

Despite these positive features related to the energetic performance and the environmental compatibility, the market share for HP technology in Italy is still hard to grow.

Therefore, this paper aims at analysing the Italian market penetration of HP technology, with a particular focus on one of the main barriers that currently limit the diffusion of such devices, which is the economic convenience compared to its main competitors.

In this regard, an economical comparative analysis is performed between HPs and gas boilers, based on several factors, such as energy costs, climatic conditions, heating needs, HP-performance classes, as well as the main economic indicators: the payback time and the interest rate. The results are presented in a parametric form, which may be profitably used for a comparative analysis with other European countries.

## 1 The residential Italian HP market

Currently, the residential Italian market is dominated by the reversible air-source heat pumps (ASHPs), mainly used for summertime cooling. However, the Italian climate, especially in the centre-southern areas, may allow the use of ASHPs as the unique heating system, both for space heating and domestic hot-water (DHW) production. This possibility could be even more substantial if the technological development of hybrid HPs (i.e. solar-HP systems) and low-temperature ASHPs was completed.

As for space heating by means of HPs, a clarification is needed about the accounting methods of renewable energy obtained by reversible ASHPs. In Italy, the Ministerial Decree DM 14.01.2012 [5] states in the VIII Technical Annex the applicable methodology when HPs deal with the national energy statistical system. The measurement of national goal achievements in terms of the renewable-energy source (RES) share for heating and cooling on final energy consumptions fulfils the Legs. Decree 28/2011, adopting EU Directive 2009/28/CE on the promotion of the use of energy from renewable sources. Annex VIII is based on a technical study on the Italian market deemed to be representative for the Mediterranean as well as by experts’
When the share of cooling-only air–air units could not be determined, as in the Italian case, air–air units are included in the statistics only for a small fraction—about 9.5%. More precisely, for the national RES contribution statistics, the reversible air–air with capacity below 17 kW account for 9.5% (revised to 10.2% since 2012) of the global sales to reduce any risk of over-estimation, since only this fraction is supposed to be used as a main heating system.

The same principle is expressed in EU Decision 2013/114 [3], where it is remarked that reversible HPs in warm and to some extent average climates are often installed with the purpose of cooling the indoor environment, although they are also used to provide heating during the winter. As the cooling demand in the summer is higher than the heating demand in the winter, the rated capacity reflects the cooling demand rather than the need for heating. As the installed capacity is used as an indicator of heating demand, it implies that the statistics of installed capacity will not reflect the capacity installed for heating purposes. Therefore, a conservative reduction to 10% for warm climates is adopted, in terms of annual equivalent heat-pump hours ($H_{HP}$), which are the assumed annual number of hours an HP has to provide heat at the rated capacity. Indeed, in support of this, the EU Decision mentions the same Italian study.

The above-described statistical methodologies reflect on the HP sales statistics. For instance, the European Heat Pump Association (EHPA), which represents the majority of the European HP industry, follows the EU Directives approach, previously detailed. Therefore, its sales data may significantly differ from other sources, which include all the equipment comparable somehow to an HP, regardless of their main usage (cooling mode, back-up heating mode, heating as unique system, etc.). In this regard, a comparison has been made between data from EHPA and Heat Pump Barometer EuroObserv’ER [6] (a European monitoring project that measures the progress made by renewable energies in many sectors in the EU), with the 9.5% correction applied to the air–air machine share. A good agreement was obtained between the two sources, so the EHPA reference will be adopted in the following.

In the European context, the Italian HP market is one of the largest: in the last 10 years, it has been always the second one, with a share between 13 and 18%. Fig. 1 shows the most recent composition by country (EU-21) and by type, according to EHPA [7]. It is worth noting that, as expected, the market in Italy is composed largely of reversible air-sourced applications.

In the past 10 years in Italy, the average annual sale volume of HPs was around 130 000, with a peak in the last 2 years, of up to about 180 000 units. In 2015 and 2016, the overall sales increased by 23 and 46%, respectively, compared with the previous year, as Fig. 2 shows [7, 8]. The introduction of a special tariff in 2014, dedicated to residential consumers using an HP as the main heating system, pushed up the market, as well as the other incentive mechanisms, even though such a tariff is currently not applicable to new applications. A further reason for the increase in those years is attributable to the weather conditions of the recent summertime seasons.

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*Fig. 1* Heat-pump market in EU-21 by type and by country in 2017 [7]
The breakdown analysis of Italy’s HP sales shows a great prevalence of the air–air split systems, as Fig. 3 shows for the 2017 market, due to the previously detailed reasons.

In terms of primary energy source, the air covers almost all the market, with a percentage of around 97%, followed by the ground with almost 3% and a negligible contribution by water [10]. Among the HPs named reversible other in Fig. 3, most are air/water type, i.e. with air as the source and water as the heat sink. Their sale volumes have almost tripled in the last 10 years (Fig. 4), being close to 33,000 in 2017 [7, 9], with an average yearly increase of more than 27% between 2014 and 2017. It should be recalled, anyway, that, currently, they cover a market share as wide as a quarter of the air–air machines. As well as a matter of costs, such a low share on the global HP sales may be due also to the practical infeasibility of a space-heating system retrofitting without replacing radiators, which represent over 90% of the current domestic equipment in households.

A positive trend is shown for the hybrid systems, which combine a gas boiler and a traditional HP (smaller than usual) in a unique integrated system, such that it guarantees the best performance related to the climatic conditions. Although it is recent technology, its increased usage is promising, with sales doubling in 2017 compared with 2015. Otherwise, DHW production by means of an HP still remains a little-used technology, presumably for cost reasons: currently, an HP for DHW production may be more expensive than a traditional electric boiler by as much as eight times, depending on size and specific features. Finally, the market of ground-source HPs was substantially flat over the last 10 years, with average annual sales below 1000 units [6], even though Italy belongs to the world top 10 countries for the electric exploitation of geothermal heat and is among the first in the EU for direct heat consumption from geothermal energy.

2 Potential and barriers

The sales rate per 1000 households is a typical index to measure the market penetration of a technology and its still unexpressed potential. In Italy, such an index was almost 7 in 2017 [7]—a value comparable with a small group of closest countries. However, compared to the Northern Europe countries, it is four to five times lower, pointing at a good increase potential. Among the main barriers, we may count the energy prices, the policy measures and incentives, and the developments in the building sector, either construction of new buildings and/or building renovations. In the last 3 years, the Italian electricity–gas price ratio (ratio between the price of electricity and the price for 1 kWh of useful heating energy delivered by natural gas) oscillated...
between 2.3 and 3.3, with an average value around 3 [11]. It should be recalled that an HP system has a comparative cost advantage over competing technologies whenever the SPF is higher than the energy price ratio.

A further barrier, not cited above, is the lack of awareness in the supply chain, for instance by the installer, who sometimes does not know the advantages of the technology or does not promote them adequately. Indeed, the technology requires an initial investment cost that is not negligible, which should be carefully explained to the end users to let them be aware of all the exploitable functionalities of an HP. When used for space heating and cooling and DHW production, HPs are the most efficient from a primary energy standpoint and also their economic payback can be shortened down to a very few years.

3 Techno–economical comparison of residential heating systems

3.1 Input parameters for the economical comparison

Comparison between the economic performances of different heating and DHW systems relies on several factors, including the building features, the climatic conditions and the specific heating plant chosen. Many of them are necessarily evaluated as average values, based on suitable assumptions and limitations, otherwise it would be impossible to conduct a comprehensible investigation because of an excessive scattering of the results. Nevertheless, the aim of the model underpinning the calculations is only to determine reference values. Indeed, when sizing a specific domestic heating system, all the previous variables are to be precisely calculated also by means of dedicated design software.

In the following, a reference dwelling will be considered with a floor area of 100 m², heated by a medium- to high-temperature heating system (water temperature at 55°C), which may be a condensing boiler or an air-to-water electric HP. Once the reference dwelling and the heating system are fixed, the heat demand for space heating and DHW are determined for each Italian climatic zone. The latter is defined according to Presidential Decree no. 412/1993 [12] and ranges from ‘A’ to ‘F’ on a heating degree-days basis, as Fig. 5 shows.

In this regard, Table 1 shows the distributions of dwellings, buildings, municipalities and resident population for each climatic zone, while, in Fig. 6, the frequency distribution of the product of degree-days and population (black solid line) measures somehow the heat demand as a function of the degree-day. In the same picture, the area between the x-axis and the frequency curve shows the overall Italian heating demand, where the rectangles state the heat-needing share for each climatic zone (measured on the secondary axis).
For each climatic zone, the dwelling average heat demand is calculated as a weighted average based on the building age and the dwelling typology, since the national real estate is not homogeneous for such features [13].

There is no perfect match between the Italian climatic characterization and the European. Indeed, while Italy is characterized by the above-mentioned six different climatic zones, EU technical rules rely on just three climatic zones: Colder, Average and Warmer, respectively, which are distinguished by the outdoor design air temperature (–22°C, –10°C and +2°C, respectively). In this work, the Italian classification has been maintained for the heat-needing of the buildings because of a very wide spread among the different climatic zones, which would lead to an excessive homogenization if they were grouped together.

Nevertheless, as better explained further on, the performance of HPs depends also on the climatic conditions and they are expressed according to EU rules, i.e. considering the three European climatic zones; therefore, a comparison is needed. Specifically in this work, the Italian climatic F zone is classified as Colder, E zone as Average, and B and A zones as Warmer. As for the climatic C and D zones, they are characterized as intermediate between Average and Warmer conditions. This classification results from an analysis of the design outdoor air temperatures of the Italian municipalities. For instance, looking at the design temperature distribution for D zone (Fig. 7), no municipalities

| Climatic zone | Dwellings | Buildings | Population | Municipalities (2016 update) |
|---------------|-----------|-----------|------------|-----------------------------|
| A             | 12 495    | 4875      | 23 488     | 7977                        |
| B             | 1 759 924 | 699 573   | 3 248 639  | 2                            |
| C             | 6 345 325 | 2 710 544 | 12 840 509 | 21.2%                       |
| D             | 7 663 173 | 2 858 016 | 14 993 476 | 24.7%                       |
| E             | 13 809 685| 5 191 960 | 27 701 135 | 45.7%                       |
| F             | 1 547 226 | 722 730   | 1 782 198  | 2.9%                        |

Fig. 6 Heat demand as a function of population and the degree-day

Fig. 7 External design temperature distribution for climatic zone D
show a value lower than –6°C, so that Average conditions would be too disadvantageous if assumed for this zone.

A statistical analysis was performed on several HP models suited for residential applications, aimed at evaluating the SCOP in different climatic conditions. As an outcome, when an HP operates in the Warmer zone, its SCOP increases by an average of 22% compared with the same performance in Average conditions. Conversely, when operating in the Colder zone, the HP has a SCOP lower by an average of 14% compared with the Average conditions. These SCOP trends are to be accounted for when calculating the electrical demand due to the heating demand, since the SCOP links the former with the latter.

Three HPs were selected, with three different energy-efficiency classes in heating mode (A, A+ and A++) according to EU Regulation 811/2013 (ErP Energy Labelling) [14], which states rules for labelling heating units, based on their efficiency (ηs). Keeping in mind that SCOP and ηs are related by the relation:

\[ \eta_s = \frac{SCOP}{2.5 - 0.03} \] (air-to-water heat pumps)  \hspace{1cm} (4)

SCOP were chosen as the mean value of the relevant class ranges in Average conditions and with a medium temperature of the water, i.e. 55°C.

As for DHW production, an L profile, defined in the same EU Regulation 811/2013, was chosen as the most suited for a mean family in a dwelling and a heat demand of 2114 kWh/y was assumed [15]. In this case, A and A+ classes were chosen related to the DHW seasonal energy efficiency. When a commercial HP is considered, the combination of the energy-efficiency classes in the heating mode and in the DHW mode would yield up to six efficiency pairs, depending on the efficiency class for the heating and the DHW production. Since the efficiency class of a fixed machine when producing hot water is usually lower than in the heating mode, the previous pairs may be reduced to the following three: A+/A_w, A+++/A_w and A+++/A+w, where the subscript h means heating mode and the subscript w means DHW production. The gas-boiler efficiency (0.9) is assumed to be constant and not dependent on the climatic conditions.

After defining the various SCOP and the gas-boiler efficiency, the annual heating and DHW demand may be calculated, in terms of electrical demand for the HP and natural gas volume for the gas boiler (standard cubic meter per year, Smc/y), with the results shown in Table 2.

3.2 Running-cost evaluation

As for the natural gas and electricity prices, they are depicted in Figs 8 and 9, taking into account the high variability of the natural gas tariffs among the six zones (Fig. 8) and the fixed costs due to the greater capacity of the electric meter, with 4.5- and 6-kW capacity (Fig. 9). The electrical consumption is calculated considering a base annual load of 2500 kWh with a 3-kW capacity. When considering the HP, an upgrade is assumed for the electric meter capacity, up to 4.5 kW for B, C and D zones, and 6 kW for E and F zones. The associated annual cost increases are then determined. All costs refer to the fourth quarter of 2018 and include taxes and levies.

With these assumptions, the annual running costs are listed in Table 3. The average SCOPs are listed too, calculated according to what has been previously described.

### Table 2: Annual electrical demand for the HP and natural gas volume for the gas boiler

| Climatic zone | Average annual heat demand (kWh/y) | Electrical demand air-to-water HP (kWh/y) | Natural gas demand (Smc/y) |
|---------------|-----------------------------------|------------------------------------------|---------------------------|
|               | A+/A_w                            | A+++/A_w                                | A+++/A+w                  |
| B             | 3894                              | 1217.0                                   | 1122.6                    | 926.9                       | 404.4                      |
| C             | 6294                              | 2014.5                                   | 1780.1                    | 1573.1                      | 653.6                      |
| D             | 10 264                            | 3370.1                                   | 2891.5                    | 2674.6                      | 1065.8                     |
| E             | 16 654                            | 5942.3                                   | 5002.4                    | 4763.6                      | 1729.4                     |
| F             | 24 534                            | 10 110.74                                | 8425.3                    | 8147.6                      | 2547.7                     |

Fig. 8 Gas cost (fourth quarter 2018) as a function of the annual consumption in the Italian climatic zones
Fig. 10 depicts the annual running-cost savings compared to the natural gas condensing boiler for each of the HPs analysed.

It may be observed that the DHW energy-efficiency class of the HP influences the total expense less and less when switching from B to F class, since the energy demand for DHW production is reduced as a fraction. From a general standpoint, significant savings may be achieved only with an A++h HP, with saving values between 28 and 33% in D zone and between 19 and 22% in E zone. In the F zone, the achievable saving is lower, at between 9 and 12%. As regards C and B zones, even if the percentage savings may seem appealing, nevertheless, the absolute savings are quite low, especially when the HP is not A++h class or A++w class at least.

3.3 Overall economic evaluation

3.3.1 Additional acceptable cost criterion

The overall economic evaluation of a technology should consider, besides the running costs, all the other costs occurring during its entire life cycle, including the capital cost, the maintenance costs and eventual fiscal incentives. In order to evaluate the possible economic advantage of an HP compared to a condensing boiler, the acceptable cost difference is calculated according to Scoccia et al. [16]. They define such concepts as the maximum allowable additional capital cost that still yields an economic gain for the HP compared to the gas boiler at the end of their operating life. Being a comparison parameter, if positive, it means that the HP is economically more profitable than the gas boiler.

The basic input data (prime cost and installation) are assumed from the catalogue of a well-known residential heating systems manufacturer, as €7374.00 and €1730.00 for HP and gas boiler, respectively. They are determined applying a 40% discount to the price list. The operating life limit is fixed at 15 years [17]. First, the additional acceptable costs are calculated without any incentives for three different HP-efficiency classes and covering the most relevant Italian climatic zones, as shown in Table 4.

Fig. 11 shows the same data as Table 4 as a function of the total SCOP (calculated as a ratio of the total thermal requirement for space heating and DHW to the corresponding electrical consumption). It clarifies that an economic advantage of an HP in climatic zones B and C would be achievable with SCOP values greater than 7.9 and 5.6, respectively—currently very far from the state of the art. As for the other climatic zones, the SCOP that provides an additional acceptable cost of zero (so-called pairing additional acceptable cost) would be available in the HP market in the near future [17]. A specific remark should be made on climatic zone F: its highly positive slope has to be related to a very limited SCOP variation with the performance HP class improvement. The latter, in turn, is due to the assimilation of this zone to the European climatic zone Colder, whose reference conditions are very far from the Average one, attributable to the E zone. Nevertheless, such an efficiency trend implies for the F zone the possible achievement of economic balance just with a small efficiency increase.

Apart from the above calculation, intended as the base case, the available fiscal incentives have to be taken into account, as the final user may rely on them. After all, if the HP is considered as a heating device only, the previous analysis shows that incentives are crucial to make this technology competitive with the gas boiler. If, instead, the HP is seen as a more complete heating and cooling device, a deeper economic analysis should be performed, with many additional parameters included, whose topics lie outside the purposes of this work.

In recent years, Italy has increased incentives with different mechanisms. One of them, available only for

### Table 3

| HP class | A+/Aw | A++/Aw | A++/A+w | Gas boiler |
|----------|-------|--------|---------|------------|
| climatic zone | Average SCOP | Annual running costs | Average SCOP | Annual running costs | Average SCOP | Annual running costs | Gas boiler | Annual running costs |
| B        | 3.20  | €340.72 | 3.47   | €320.52 | 4.20 | €278.60 | €424.84 |
| C        | 3.12  | €511.53 | 3.54   | €461.35 | 4.00 | €417.00 | €617.26 |
| D        | 3.05  | €801.88 | 3.55   | €699.37 | 3.84 | €652.91 | €977.12 |
| E        | 2.80  | €1387.92 | 3.33 | €1186.60 | 3.50 | €1135.45 | €1457.51 |
| F        | 2.43  | €2280.67 | 2.91   | €1919.71 | 3.01 | €1860.24 | €2118.62 |
private citizens, guarantees a tax deduction (up to 65% of the investment, including installation costs) for the replacement of the old heating system or the old electric heater for DHW. Both HPs and gas boilers comply with this fiscal mechanism.

When the fiscal incentives are taken into account, the additional acceptable costs become those shown in Table 5. Incidentally, it should be noted that the net impact of the incentives is to raise the additional acceptable costs by a fixed amount for all the examined cases, namely

![Graph showing annual running cost savings as a function of HP SCOP](https://academic.oup.com/ce/article-abstract/3/2/126/5393281)

**Fig. 10** Annual running-cost saving percentages

**Table 4** Additional acceptable cost of heat pumps—without any incentives

| Climatic zone | $A_{h}/A_{w}$ | $A_{++h}/A_{w}$ | $A_{++h}/A_{+w}$ |
|---------------|----------------|----------------|------------------|
| B             | €4381.70       | €4078.68       | €3449.85         |
| C             | €4057.58       | €3304.78       | €2639.53         |
| D             | €3014.95       | €1477.36       | €780.47          |
| E             | €4599.66       | €1579.87       | €812.70          |
| F             | €8074.33       | €2659.93       | €1767.87         |

**Table 5** Additional acceptable cost of heat pumps—incorporating any incentives

| Climatic zone | $A_{h}/A_{w}$ | $A_{++h}/A_{w}$ | $A_{++h}/A_{+w}$ |
|---------------|----------------|----------------|------------------|
| B             | €713.41        | €410.39        | €218.44          |
| C             | €389.29        | €363.51        | €1028.76         |
| D             | €653.34        | €2190.93       | €2887.82         |
| E             | €931.37        | €2088.42       | €2855.59         |
| F             | €4406.04       | €1008.36       | €1900.42         |

![Graph showing additional acceptable costs as a function of HP SCOP](https://academic.oup.com/ce/article-abstract/3/2/126/5393281)

**Fig. 11** Additional acceptable costs as a function of HP SCOP
something more than €3650 so that the HP becomes suited in almost all the analysed conditions (Fig. 12).

Finally, it should be recalled that climatic zones D, E and F, where the additional acceptable cost may be positive with a suited HP-efficiency class, include almost 75% of the Italian population, corresponding to 85% of the overall residential heat needed in the country.

3.3.2 Net present value (NPV) criterion

The economic analysis may be carried out also comparing the NPV of the various heating systems. NPV is defined as the difference between the present value of cash inflows and the present value of cash outflows over a period of time and is usually used to analyse the profitability of a projected investment or project. In the current case, since a heating system does not generate cash inflows itself, it will be used just as a comparison tool between the alternatives analysed. In fact, all the calculated NPVs will be negative and the best investment will correspond to the less negative one. Considering the same consumption and investment data previously fixed and a 3% annual interest rate, the calculated NPVs are summarized in Fig. 13. In practice, NPV differs from the additional acceptable cost in that it takes into account the monetary revaluation according to the fixed interest rate, so that the global profitability trends are almost the same with both the economic indicators. They would coincide exactly if a 0% annual interest rate was assumed.

Corresponding data are reported in Table 6. By looking at the differences between the column of the boiler and the various HPs’ NPVs, results similar to those shown in Fig. 12 are achieved, as Fig. 14 reports.

The obtained NPVs are in good agreement with those obtained in a similar study regarding the economic comparison of heating systems for residential buildings [18] in some European climatic conditions.
From the previous figure, the economic convenience of some cases becomes questionable if compared to the additional acceptable cost analysis. In particular, two cases, which were slightly positive in terms of additional acceptable cost, turn negative when their NPVs are considered instead. After all, it should be remembered that the NPV analysis is the most suitable when an economic investment approach is adopted.

3.4 Sensitivity analysis

A sensitivity analysis may be carried out also by varying the most relevant variables, for instance the heating needs, the gas and electricity prices, the interest rate and the payback time.

The space-heating needs were varied between −50 and +50% of the case base, while fixing the gas and electricity prices. The SCOP values were varied accordingly, as they are influenced by the share of the space-heating needs and DHW on the global consumption. As for the incentives, in the following analyses, they will be always taken into account.

The results are depicted in Figs 15–17. If an HP A+hAw is considered (Fig. 15), it can be observed that it is almost always not competitive if compared to a gas boiler, with the exception of climatic zone D, where it is cheaper down to...
–20% of base heating needs. The use of such an HP could provide advantages also in climatic zones C and E, although they are very small and only for high heating needs (at least 30–40% over base heating needs). The negative slope of the F climatic zone curve is notable, due to an unfavourable ratio between the electricity and the gas prices.

With an A++hA+w class (Fig. 16), the use of an HP in climatic zone B is practically always disadvantageous. As for the C and F zones, an economic gain results until the heating needs are reduced by down to 20% compared to the base case. In zones D and E, the economic gain may be relevant, even in case of very high reduction of the heating requirements.

Finally, an A++hA+w HP (Fig. 17) is economically advantageous in almost all the analysed conditions. Negative values of the additional acceptable cost would be achieved only in climatic zones B and F with a heating-needs reduction greater than 20 and 40%, respectively.

The prices of natural gas and electricity affect the economic analysis. This effect can be investigated by varying them within a ±20% range. For the sake of simplicity, the best-performing HP class is represented only, i.e. the A++hA+w class, which shows the additional acceptable cost according to Fig. 18 for the gas-price variations and Fig. 19 for the electricity. In both cases, the other variables are referred to the base case.
Referring to the gas-price variation, the stronger dependence is observed in climatic zone F, consistently with its highest consumption level. A first remark concerns climatic zone D, where the economic convenience of an HP is always guaranteed, even in the case of a reduction in the gas prices, at least down to –20%. On the contrary, using an HP in climatic zone B is not convenient starting from a reduction in the gas price of about –3.5%. For the other climatic zones, the maximum reductions, which correspond to a still positive additional acceptable cost, are about –6% for the F zone, –11% for C zone and –13% for E zone.

The electricity price acts in the opposite direction to the gas price, as Fig. 19 illustrates. For instance, in climatic zone D, the economic convenience lasts up to electricity-price increases greater than 20%. In climatic zones C and E, a positive value of the additional acceptable cost is kept as long as the price increase is lower than about 16.5%, while, for B and F zones, this value is around 5 and 7%, respectively.

The base life-cycle time is considered as fixed at 15 years, but a brief analysis of such a parameter may provide some further elements for a complete sensitivity investigation. All three HP classes are looked into and the payback time is varied between 5 and 20 years, with the trend curves depicted in Figs 20–22.

When the worst-performing HP class is considered (Fig. 20), the additional acceptable cost is practically positive only in climatic zone D until the payback time is at least
greater than 11 years. In the other climatic zones, the additional acceptable cost is substantially always negative. The negative slope of the F-zone curve due to the negative running-cost difference between the HP and the boiler is noticeable (as shown in previous Fig. 10 and Table 3).

The payback time variation affects the A++A HP class, as shown in Fig. 21. In particular, it is possible to get a positive additional acceptable cost even with payback times are lower than 10 years (zones D and E). In climatic zones C and F, a positive value of additional acceptable cost may be achieved in a reasonable time, namely between 10 and 13 years. In climatic zone B, a longer time would be needed—much longer than the lifetime of such technologies.

If an A++A HP class is considered (Fig. 22), the times to get positive acceptable costs are obviously shortened compared to the previous cases. The economic convenience may be achieved also for climatic zone B, with a time of about 14 years.

In Figs 21 and 22, the curve trends for climatic zones D and E are almost overlapping, due to the concurrence of the absolute running-cost variations for the HP and the boiler (see Table 3) when moving on the two climatic zones.
Finally, in order to evaluate the effects of a variation in the interest rate, the NPV indicator is calculated for the interest rate varying between 0 and 10%. As done for the base case analysis, the NPV differences between the HPs and the boiler will be calculated so that positive NPV differences will correspond to the economic convenience of the HP over the gas boiler.

From the previous figure, an A+A class HP is not convenient in any climatic condition or for any interest rate, with the exception of climatic zone D, where NPV is positive up to about a 4.5% interest rate.

When dealing with an average-performing HP, that is an A++A class, Fig. 24 shows that, in climatic zones D and E, an NPV positive value is obtained for every value of the investigated interest rate. In climatic zones F and C, positive NPVs may be obtained with interest rates lower than about 6.5 and 2.5%, respectively. For climatic zone B, the A++A HP is never economically convenient.

If the best-performing class is considered, i.e. the A++A+ class, Fig. 25 shows that it is economically more competitive than the gas boiler in almost all the climatic zones. In particular, for climatic zones D, E and F, it is convenient over all the interest rates investigated, while, in climatic zones B and C, positive NPVs will be obtained until the interest rate is lower than about 1.5 and 6.5%, respectively.
As for the overlap of curves of climatic zones D and E, the same comments as for Figs 21 and 22 apply.

4 Conclusions

The Italian HP market is currently one of the most important in Europe, having grown from nothing 10 years ago up to some 180,000 units sold last year. Potentially, further deployment could be expected, as the penetration index is considerably lower than the best-performing countries. After some years of relatively stable sale volumes, the Italian HP market has recently experienced a good increase, with 23 and 46% annual increases in 2015 and 2016, respectively.

The leading sector still remains the air–air reversible domestic application, since historically they caught on as summer cooling machines, especially against the Italian warm climatic conditions of recent years.

As for the air–water HP applications, which are the most complete technology for space heating and cooling and DHW production, an economic analysis was performed in order to evaluate their economic advantage compared to the gas boiler. The main parameters considered were the climatic conditions, the heating needs, the HP-performance class and the gas and electricity prices. Financial incentives were taken into account too, as well as the main economic indicators: the payback time and the interest rate. A base case was defined by assuming

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Fig. 24 NPV difference (boiler – HP) as a function of interest rate: A++A, HP class—incents included

Fig. 25 NPV difference (boiler – HP) as a function of interest rate: A++A+, HP class—incentives included
reference values for the main parameters. Both running and overall costs were determined. A sensitivity analysis was conducted as well, in order to evaluate the effects of varying many parameters, such as the heating needs, the gas and electricity prices, the interest rate and the payback time.

Among the relevant results, the main are as follows:

- In climatic zone D, which accounts for almost a quarter of the population, an economic advantage results by using an HP instead of a gas boiler, in terms of both additional acceptable cost analysis and NPV criterion. This advantage is practically maintained with every performance class and even in case of strong variation in the heating needs, the gas and electricity prices, the interest rate and the payback time.

- In the most populated Italian climatic zone E, the economic convenience of a heat pump with respect to a gas boiler, on a heating and DHW basis, depends essentially on the HP class. In fact, both the additional acceptable cost and the NPV differences are positive with an A++A or A++A+ class and negative otherwise. The economic advantage is guaranteed within the wide limit of the investigated parameters only with an A++A+ HP.

- In climatic zone B, the use of an HP is never economically convenient. This result has to be balanced in light of two considerations: first, a very low heating need in this zone; second, a very low percentage of population involved (around 5%); the adoption of such technology in this climatic zone may be justified only by including the cooling-needs analysis (which is outside the scope of this work).

- In climatic zone C, the additional acceptable costs are slightly influenced by the HP class, and rather low economic gains may be achieved in the base case, even with the best-performing HP. This is confirmed also by the trend in the NPV differences. The sensitivity analysis showed an economic advantage of an A++A+ HP related to the investigated gas- and electricity-price variations, while payback times lower than 15 years may be achieved also with an A++A HP. A certain influence of the interest rate on the economic convenience was highlighted as well.

- As regards the climatic F zone, it should be recalled that it is considered as belonging to the most severe of the European climatic zones, i.e. the Colder, and it is the least populated. Moreover, it is characterized by the highest heating needs. If the worst performance class is excluded, the analysis showed good trends in the base case. However, when dealing with the gas- or electricity-price variations, their high influence on the additional acceptable cost and the NPV differences makes an HP an application subject to significant fluctuations of running costs, so its economic convenience has to be more carefully investigated.

Fiscal incentives, or similar mechanisms allowing a reduction in the investment costs, are crucial to the competitiveness of HP technology, considered as a viable heating alternative to the condensing gas boiler.

HP technology is capable of providing significant economic advantages in many conditions (provided that the above-mentioned incentives are taken into account). However, the current market sales still show an unexpressed potential, as detailed in the paper. Therefore, a broader diffusion of HP technology could start by removing the other limiting barriers, for example, by increasing the awareness of suppliers, installers and end users. Moreover, a substantial boost may arise from building-renovation and new-building construction.

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