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Energy, economic and environmental modelling for supporting strategic local planning

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Abstract

This study investigates the use of an evaluation model able to estimate the possibilities of reducing energy consumption and emissions of the building sector exploiting renewable energy sources. Specific attention is given to the use of ground source heat pumps in the urban context, proposing an ex-ante evaluation of different scenarios to identify the most balanced one in terms of energy, economic and environmental effects. The model is applied to a case study in Northern Italy to show how it can be used to support local administrations in energy urban planning, fitting economically and environmentally sustainable technologies. Moreover, it defines new boundaries in which the energy and environmental analyses should be carried out (spatial relocation), and the time span over which impacts have to be evaluated (temporal relocation).

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Keywords: Local energy planning; energy retrofit; economic feasibility; Ground Source Heat Pumps; CO_2 emissions

1. Introduction

In line with EU Roadmap 2050, it is fundamental to use renewable energy sources to mitigate environmental impacts of the energy sector [1]. The future energy system will be distributed, heavily relying on renewable energies,

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efficient use of energy, challenging all governance levels. At present, integrated low carbon policies and sustainable energy plans are affected by common challenges. At the local level, energy policies employ community and regional instruments limited to the energy performance of buildings. A proper transposition of the regulatory framework into municipal laws and plans is insufficient at the moment and the enforcement uneven. In particular, the current administrative organization shows to have poor knowledge and skills needed to perform updated planning.

Evaluation tools able to guide public administrations in low-carbon energy planning are essential. For this reason, a model for supporting local energy planning is developed with the objective of helping decision makers in defining energy policies at local level. In detail, the model aims to assess energy, economic and environmental impacts of alternative energy scenarios related to the use of low enthalpy geothermal heat pumps. The proposed model has been experimented on a real case study, the historical centre of Livorno Ferraris (Vercelli, Northern Italy). This case is particularly significant as the town that in the current state is never been regenerated from the point of view of energy, and represents the starting point to evaluate the maximum potential achievable by renewable sources for energy demand reduction. The EU Roadmap considers heat pumps as the main technology to achieve the objective of 100% renewable heating network. Heat pumps can use air or ground as heat sources. Heat pumps and, above all, Ground Source Heat Pumps (GSHPs) allow significant economic savings [2], which mostly depend on the ratio between the prices of gas and electricity [3]. GSHPs are divided into two main categories: closed-loop, based on the circulation of a heat carrier fluid in a closed pipe loop buried into the ground (Bore-hole Heat Exchanger, BHE), and open-loop, based on the thermal exchange on groundwater (Ground Water Heat Pump, GWHP). BHEs can be installed almost everywhere, since they do not require the presence of a productive aquifer. In addition, the design and authorisation of these plants is simpler. For these reasons, they are often used for small-size installations, i.e. up to 50 kW, while open-loop systems are more diffused for large-size plants up to some MWs of power [4], for which noticeable scale economies are achieved compared to the closed-loop solution. GWHPs efficiency is generally higher com-pared to BHEs, however they can only be installed where groundwater is present. Scale economies allow GWHPs to be used also for District Heating (DH) [5], for which closed-loop systems would hardly be viable. Individual heat pumps and DH are the core of the Heat Roadmap Europe [1] to achieve a 100% renewable heat production by 2050.

2. Methods

After having contextualized the potential of GSHPs in the section above, the goal of this second part is to study its application to the case study. This analysis considers the creation of a low-energy neighbourhood, for which a major share of the heating energy needs is covered by renewable energy production to reduce greenhouse gasses (GHGs) emissions. In particular, air- and groundwater heat pump systems are designed to achieve the objective. The case study is the historical town centre of Livorno Ferraris (Northern Italy). The neighbourhood extends over 7.6 hectares, and the total heating area of buildings is equal to 68,420 m². Most of the buildings located in this area were built before 1980, and then the thermal performances of envelopes are low. Also, some historical buildings, such as the old town hall and library built before 1800, are in this area. Different topologies and use purpose of buildings could be recognized. Nine building typologies distinguished by common features and characterized by comparable consumptions are identified, according to the TABULA database [6]. Once typified the neighbourhood buildings, the current annual thermal energy needs for heating were calculated (Table 1).

For the energy refurbishment of the historical centre, the substitution of the current conventional heating systems, which consist in high efficiency traditional boilers, with heat pumps was studied. Two different scenarios were evaluated: the first scenario (A) considers the installation of several geothermal and air-source heat pump systems, each one serving a cluster of buildings, while the second (B) investigates a district heating (DH) solution, requiring the installation of a heat pump station located outside of the town. Since a very productive aquifer underlies the analysed area, GWHPs were considered in this study rather than BHEs, due to their higher efficiency. In the scenario A, the buildings were divided into 27 clusters considering the different blocks of the town centre and the accessibility for drilling machines. Well locations were identified on the map and a GWHP well doublet was assigned to each cluster to meet its aggregated energy demand. Air-Source Heat Pumps (ASHPs) were considered for 10 clusters for which accessibility issues could arise for well drilling machines. However, only 17.4% of the total heat demand is covered by these 10 air-source heat pumps, while 82.6% is covered by GWHPs. In the scenario B, a