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Assessment and mapping of the shallow geothermal potential in the province of Cuneo (Piedmont, NW Italy)

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ABSTRACT

Ground Source Heat Pump (GSHP) is a low carbon heating and cooling technology which can make an important contribution for reaching the ambitious CO_2 reduction targets set by the European Union. The economic and technical suitability of this technology strongly depends on the thermal and hydrogeological properties of the ground at the installation site, which need to be assessed in detail. A common indicator adopted to define such suitability is the geothermal potential, i.e. the thermal power that can be exchanged with the ground through a GSHP with a certain setup. In this paper, we present the assessment and mapping of the shallow geothermal potential in the province of Cuneo, a 6900 km^2 wide county in NW Italy. Geological, hydrogeological and climatic information are collected and processed to estimate the relevant ground properties. The shallow geothermal potential is then estimated with different methods for closed-loop installations (Borehole Heat Exchangers, BHEs) and open-loop installations (Ground Water Heat Pumps, GWHPs) systems in order to identify the most suitable areas for different technologies. The maps of the geothermal potential are an important planning tool for the installation of GSHPs and for the growth of this renewable energy source.

1. Introduction

The European Union recently set three ambitious objectives for its energy policies: by the year 2020, the total energy consumption and the Greenhouse Gas emission have to be cut by 20%, and 20% of the total energy consumption should be covered by Renewable Energy Sources (RES) [1]. Italy has already achieved its national target in 2014, with 38.6% of the electricity and 18% of the heat production provided by RES [2], one of the best performances among EU Member States [1]. To achieve further improvements in alignment with Roadmap 2050 [3], efforts should now concentrate on heat production, for which the most adopted RES are ligneous biomass (68.9%) and heat pumps (25.8%) [2]. A further expansion of biomass heating is hardly sustainable, due to its impact on air quality [4,5]. On the other hand, heat pumps have zero emissions on site and reduce GHG emissions up to 90% compared to fossil fuel burners, depending on the energy mix adopted for the production of electricity [6,7]. In Italy, about 60% of the total production of electricity is covered by fossil fuels, with an emission factor of 326.8 g CO_2/kWh [8]; the consequent reduction of CO_2 production, according to Saner et al. [7], is of about 50% compared to a methane boiler.

Heat pumps are divided into two main categories: Air Source (ASHP) and Ground Source (GSHP). The main advantage of GSHPs compared to ASHPs is the higher COP, thanks to the lower temperature difference between the heat source (ground or groundwater) and sink (heating/cooling terminals) [9]. GSHPs have proved to be a cost-effective solution for a wide range of buildings, despite the additional expense for the installation of the ground heat exchangers.

GSHPs in Italy still account for only 0.1% of the total thermal energy production [2]. However, a continuously increasing trend has been observed in recent years (+13% in 2013), and a strong rise is expected for the next 10–15 years [10,11]. The high cost of installation is widely acknowledged as a limiting factor for the increase of heat pump installations and, particularly, for geothermal heat pumps. In Italy, another major barrier is the high cost of electricity for domestic supply, compared to the relatively low cost of methane [12]. As a consequence, compared to other countries, a lower saving margin is achieved for heat pumps against fossil-fuelled boilers. The problem of the higher cost of installation has been addressed introducing a strong tax refund (65%) on energy

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retrofit works of existing buildings, among which GSHPs are included [13].

The lack of homogeneous and targeted regulation is another barrier for the growth of shallow geothermal energy in Italy [14]. This absence of regulation has been partially filled with voluntary schemes and standardization [15], such as the recent UNI standards for GSHPs [16–18].

A final problem is that the technology and the potential of shallow geothermal energy are still little known in most EU countries. A number of EU-funded projects have been conducted in recent years to disseminate knowledge on GSHPs with training events, workshops, and case studies [19–21]. These projects raised the different stakeholders' awareness of the potential applications of shallow geothermal energy.

However, the suitability of different territories for GSHPs needs to be studied on the small scale, since it depends on site-specific parameters and on the technology adopted [22–24]. A commonly adopted indicator is geothermal potential, which is defined in different ways, but can generally be identified as the capacity of the ground/aquifer to provide heating and/or cooling [25–31]. Some projects have already been conducted in Italy to assess shallow geothermal potential. Busoni et al. [26] assessed and mapped the suitability for the installation of BHEs of the province of Treviso (Veneto, NE Italy). Their work took into account ground thermal conductivity, geothermal gradient and groundwater velocity. The VIGOR project [28,29] addressed both shallow and deep geothermal energy potentials of four regions in Southern Italy (Campania, Apulia, Calabria and Sicily). In situ measurements of the thermal conductivity of rocks [28] were conducted over the mapped territory, and the potential for GSHPs was mapped for both heating and cooling purposes [29]. Gemelli et al. [30] assessed the shallow geothermal potential of the Marche region (Central Italy), evaluating the required BHE length to cover a standard thermal load. Fewer studies have been performed for open loop Ground Water Heat Pumps (GWHPs), such as the works of Arola et al. in Finland [25]. Lo Russo and Civita provide an overview of the hydrodynamic properties of shallow unconfined aquifers in Piedmont (NW Italy) [31].

The aforementioned studies provide a methodological basis for the work presented in this paper. Here, the shallow geothermal potential in the province of Cuneo (Piedmont, NW Italy) is assessed and mapped. The geological and hydrogeological setting of this territory is studied, and a conceptual model is provided to correlate this setting with ground thermal parameters. These are the input for the estimation of the closed-loop geothermal potential with model G.POT [27]. The geothermal potential for open-loop systems was evaluated by estimating the maximum extractable and injectable flow rates of the shallow aquifers of the Cuneo plain, based on a dataset of well tests results. Conclusions are drawn on the suitability of different areas of the province of Cuneo for closed and open loop geothermal heat pumps.

2. The territory surveyed

The province of Cuneo is a 6900 km^2 wide area located in the south-western edge of Piedmont. It can be subdivided into three main parts (Fig. 1): the Alpine valleys (Cotian and Maritime Alps) on the western and southern edges, covering about 51% of the total surface, the plain in the centre of the Province (22%) and the hills of Langhe and Roero in the East part (27%).

The total population is 592,060 inhabitants, of which 35% live in the county seat Cuneo (56,113 inhabitants) and 6 other main towns in the plain (Alba, Bra, Fossano, Mondovì, Savigliano and Saluzzo) of 15,000 to 30,000 inhabitants. The rest of the population mostly lives in rural villages on the plain, while a small part lives in the mountains and the hills.

In this chapter, the province of Cuneo is described from the climatic, geologic and hydrogeological points of view, and data is provided for the assessment of the shallow geothermal potential.

2.1. Climate

Cuneo is characterized by a continental climate with a cold winter and a mild summer, as reported in Fig. 2A. Although the distance from the sea is quite short (30÷100 km), a weak influence of the Mediterranean sea is observed, due to the isolating effect of the Alpine chain. The total rainfall varies widely, from 700÷900 mm/y in the hills of Langhe and Roero to 900÷1200 mm/y in the plain and in the mountains [32]. The annual mean air temperature is strongly correlated with the ground elevation, as shown in Fig. 2B, ranging from −3.1 °C to +13.2 °C [33]. The climate of Cuneo and its province is therefore one of the coldest in Italy, thus influencing the distribution of the heating degree-days (Italian DPR 412/1993 [34]). 66% of the population lives in climate zone E (2400÷3000 heating DD) and 34% lives in climate zone F (>3000 DD). As a consequence, the expense for house heating is one of the highest in Italy, while almost 90% of homes have no chilling plant [35].

2.2. Geology

The mountainous portion of the territory surveyed is located on the boundary between the Helvetic and the Penninic domains of the Alps [36] and, according to the geological map of Piedmont [37] reported in Fig. 3, it is mainly composed of gneiss, and, to a lesser extent, limestone, calceschysts, serpentinites, sedimentary rocks (conglomerates, sandstone, gypsum, consolidated clays) and granite.

The plain is composed of locally cemented sand and gravel sediments deposited in the Holocene (12,000 years BP), with small loamy and clayey lenses. This alluvial cover lies on the Tertiary Piedmont Basin, composed of marine sediments settled during the Pliocene and the Villafranchian (5÷1 Ma BP) [31,38].

The East part of the province of Cuneo is occupied by the hills of the Langhe, on the right bank of the Tanaro river, and of Roero, on the left bank. These hills were formed by the local uplifting of the Tertiary Piedmont Basin (Langhian, 16÷13 Ma BP) [39] and the excavated by the tributaries of the Tanaro river after the capture of this watercourse, occurred in the Riss-Wurm interglacial period (250,000 years BP). Langhe hills are mainly composed of Miocene marls and sandstones (23÷5 Ma BP), while Roero hills are composed of fine sands and clays deposited during the Pliocene (5÷2.5 Ma BP).

2.3. Hydrogeology

The capture of Tanaro affected not only the morphology of a large part of the territory surveyed, but also the underground water circulation. Indeed, the deepening of the river bed of Tanaro's tributaries transformed them into hydraulic divides of the alluvial unconfined aquifer, which is composed of three main portions [32] (Fig. 4): the *Left Stura Bank* and the *Right Stura Bank*, separated by the river Stura, and the *Tanaro Valley* along the river.

The *Left Stura Bank* is a large aquifer (1117 km^2) in the Western sector of the plain. The subsurface flow is directed from SW to NNE (Fig. 4A) and the hydraulic gradient gradually diminishes from 10‰ on the West and South edges to 2‰ in the North part of the plain. The transmissivity is very high (up to 0.1 m^{2}s^{-1}) in the centre and diminishes on the eastern edge, with a concurrent reduction of the saturated thickness (Fig. 4B) of the aquifer [31]. The depth to water