The role of standards and regulations in the open-loop GWHPs development in Italy: the case study of the Lombardy and Piedmont regions

The role of standards and regulations in the open-loop GWHPs development in Italy: the case study of the Lombardy and Piedmont regions

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Abstract

Groundwater Heat Pump systems (GWHPs) represent one of the most suitable technologies to be applied for heating and cooling purposes in buildings. This paper explores the urban and regional standards and regulations with which Piedmont and Lombardy Regions (Northwestern Italy) are equipped: the in-force regional and municipal regulatory references to which a new geothermal project must comply (i.e., authorization requests and plant final testing operations) were taken into consideration, highlighting the potential and limits connected to different diffusion rates of GWHP systems by means of the Turin and Milan cities contexts analysis. To promote a rapid but sustainable diffusion in the medium and long period of open-loop geothermal solutions in densely urbanised contexts, urban planning instruments must pursue the following aim: to ensure adequate long-term protection of the groundwater bodies, through an understanding of the subsoil in the decision-making process heating and cooling of buildings in densely urbanised areas. The multilevel analysis performed is proposed as a guide to allow professionals to understand the various regulatory processes that guide the authorization methods of new geothermal plants.

Keywords: geothermal energy system; groundwater heat pump system; urban energy policy; Italy

1. Introduction

As reported in the REN21's Renewables in Cities Global Status Report (REC) about 70% of the European population lives in cities and urban areas account for a similar share of energy consumption and greenhouse gases emission. As such, cities and local authorities are crucial vehicles for implementing climate and energy objectives and sustainability goals. Since 2008 more than 10,000 European cities and 43 European countries have signed the "Covenant of mayors for energy and climate for the integration of renewable energy in building heating", aiming at promoting collaborative policies between local governments voluntarily committed to achieving and exceeding the 2030 and 2050 EU climate and energy targets [1]. Urban and regional planning policies encouraging medium and long-term political commitment and concrete local action to address the climate adaptation challenge, as well as energy poverty, are increasingly needed. As part of the initiative above-reported, cities have undertaken to meet and exceed European targets in terms of CO_2 emissions reduction of at least 40% by 2030, demonstrating a level of ambition often higher than the national level of the respective countries [2].

At a national scale, Italian urban areas turn out to be characterised by centuries-old infrastructure: 35% of the Italian buildings stock is made up of buildings built before 1970 [3] and about 75% is thermally inefficient [4]. In this scenario, a significant obstacle lies in the gradual reduction of total energy requirements and the correlated greenhouse gas emissions by incorporating existing renewable energy solutions into buildings. [5–8]. Among available renewable energy sources (RES), shallow geothermal energy is a promising low-carbon option for fulfilling the energy requirements of urban buildings, particularly in temperate regions [9,10]. In closed-loop ground-source heat pump systems (GSHPs) exchange heat with the subsoil through one, or multiple borehole heat exchangers (BHEs) installed at depths of up to 200 m [11–13]. Conversely, in an open-loop groundwater heat pump systems (GWHPs) groundwater is extracted from an aquifer or similar source and conveyed to the heat pump, where it transfers its heat through the evaporator. Subsequently, the water is either reintroduced into the ground or released at the surface [14,15]. Despite their not widespread application at the national level, GWHPs presently stand out as highly appropriate technologies for heating and cooling buildings. As described in [16], the performances of GWHPs strongly depend on the heating and cooling required thermal loads, heat pump design characteristics (e.g., compressor efficiency and heat exchanger configuration), control strategies, and aquifer characteristics (e.g., groundwater temperature, thermal and hydraulic conductivity of geological formations). Besides, depending on the use mode (heating or cooling), energy can be extracted or injected into the shallow aquifer. The reinjection of a thermally perturbed amount of water in the exploited aquifer has the potential to cause, even in the short term, significant environmental impacts associated with the origin of a thermally affected zone (TAZ). Therefore, identifying alternatives to discharge in the shallow aquifer (i.e., surface rivers), especially for densely urbanised areas, is often necessary [17,18]. Because of the above-described environmental limit, urban and regional policies for encouraging the diffusion of open-loop systems in urban areas cannot be disregarded the knowledge about geological and hydrogeological settings. Ensuring that the increase in the GWHPs diffusion rate is sustainable in the medium and long period, in terms of thermal impact on groundwater resources, is essential. Therefore, the introduction of new planning standards and regulations must simultaneously pursue a dual objective: 1) to allow for rapid diffusion of open-loop groundwater heat pumps (GWHPs) and 2) to ensure adequate medium and long-term aquifer’s protection, by taking into account the hydrogeological properties of the subsoil during the decision-making and authorization process. In the described process, the development of a numerical simulation model plays an important role, also in forecasting the TAZ's propagation modalities over time [19–21].

A comprehensive and multi-level analysis of the urban and regional planning standards and regulations with which some Italian regions (Piedmont and Lombardy Region) are equipped is proposed in this paper. In detail, the main regulatory references to which a geothermal project must comply concerning the in-force national, regional, and municipal regulations (i.e., geothermal wells drilling authorization requests and plant final testing operations) were taken into consideration and summarised through a schematic approach. The various regulatory instruments analysed pursuing the above-described objectives were tested, also performing an analysis of the diffusion rates of GWHPs in two different contexts at an urban scale: the comparison between the cities of Turin and Milan represents a useful tool for researchers and professionals for properly depicting and identifying the peculiarities and criticalities of both hydrogeological contexts in terms of allowing GWHPs diffusion.

2. Materials and Methods

2.1 Renewable Energy Sources: Italian development framework

Italy plans to pursue the target of obtaining 30% of gross final energy consumption from renewable sources in 2030 (Article 3 of Directive (EU) 2018/2001 [22]), by defining a pathway of sustainable growth for RES and their full integration into the system. In detail, 33.9% is expected to be the contribution from RES in the heating sector [23]. Currently, the share of RES in the thermal sector is limited to the 20% (Figure 1).

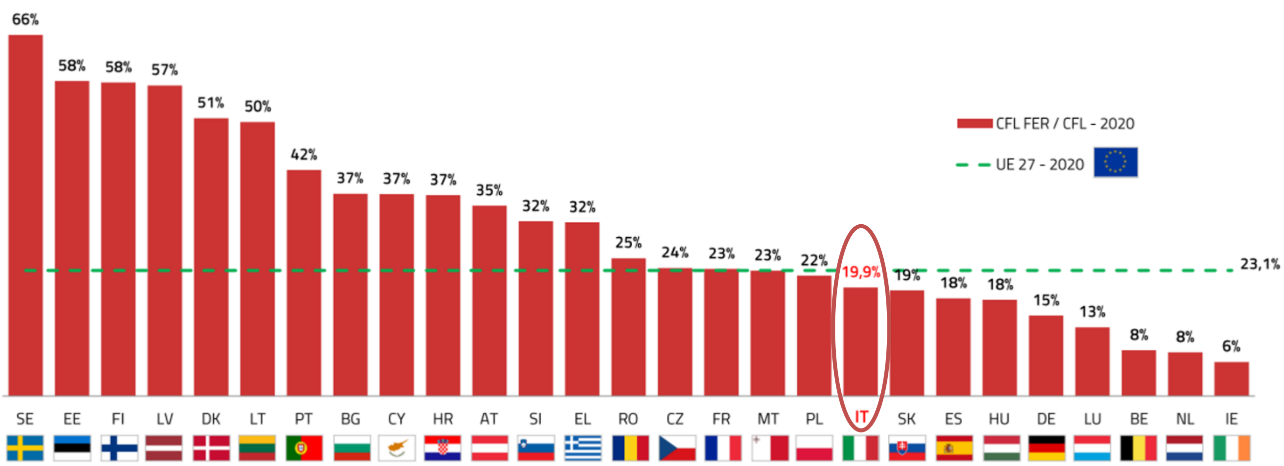

Figure 1 Percentage of gross energy consumption covered by renewables in the thermal sector and the overall EU27 average (modified from [24]).

Italy is one of the top 10 countries for geothermal electricity generation [25] and among the first 15 for heating and cooling applications [11]. In 2020 the geothermal energy capacity for thermal use exceeded

1300 MW_{th}, with a corresponding total energy use of 9668 TJ/yr. The main sector of utilization is the space heating of the buildings, which accounts for 41% and 49% in terms of installed capacity and energy use, respectively [26]. In 2021, there were 226 active installations in Italy for the exploitation of direct geothermal energy for the sole heat production purposes. These are, in most cases, individual heating and thermal plants [27].

The heating sector is expected to play a major role in achieving the Italian RES medium to long-term targets. A decisive technological shift towards increasingly new RES solutions is required: the diffusion of open and closed-loop heat pumps is a key instrument to decarbonise existing thermal energy systems.

At present, it is challenging to accurately measure the distribution of geothermal heat pump systems in Italy. To date, no national census is available for consultation, and only a very few local authorities have a plant register. Moreover, the absence of a univocal regulatory framework results in a high fragmentation of the few available data, difficult to compare because they refer to different systems (in some cases the data refer to water-based heat pumps; in other cases, to vertical closed-loop systems or any closed-loop geothermal configurations).

A national restructuring of regulations concerning the exploration and exploitation of geothermal resources was proposed through the Legislative Decree no. 22 of February 11, 2010 [28]. According to Article 10 of the Legislative Decree no. 22 small local uses of geothermal heat are those that simultaneously meet the following conditions: a) Allow the implementation of systems with thermal power less than 2 MW, obtainable from geothermal fluid at the conventional temperature of effluents of 15 degrees Celsius; b) Are obtained through the drilling of wells up to 400 meters for the exploration, extraction, and use of geothermal fluids or hot waters, including those flowing from springs, for a total thermal power not exceeding 2,000 kW. Small local uses of geothermal heat also include those carried out through the installation of geothermal probes that exchange heat with the subsurface without withdrawing and reinjecting hot water or geothermal fluids into the subsurface. In connection with this last type of local use, the Legislative Decree issued on September 30, 2022 [29] represents the first effective tool for formalizing and regulating the construction of closed-loop geothermal plants. National guidelines governing the establishment of facilities dedicated to heat production from above-mentioned geothermal systems, specifically for building heating and air conditioning, are outlined here. Such a legislative instrument is still absent for GWHPs. The Regions continue to be the competent authorities for administrative tasks, including supervision, related to the small local applications of geothermal heat through GWHPs.

Existing regulatory instruments are pursuing the objective of providing incentives to promote the diffusion of RES energy systems in buildings:

- Tax deductions for energy efficiency measures and restoration of existing buildings;
- Thermal Energy Account (“Conto Termico” in Italian);
- White Certificates System, including the promotion of high-efficiency cogeneration systems;
- Contributions to municipalities towards investment in the field of energy efficiency and sustainable local development.

All the above-reported measures operate at a national level. In detail, the tax deductions for thermal renewables energy, introduced in 1997 and still in place, have covered the installation of solar thermal systems, geothermal systems installations in buildings, the replacement of existing winter heating systems, and biomass installations. The Thermal Energy Account, introduced with the Italian Ministerial Decree of 28 December 2012 [30], provides incentives for the replacement of existing heating systems with new ones, including combined systems for the production of domestic hot water, equipped with electric or gas heat pumps. Besides, white certificates are tradeable goods which certify the achievement of a reduction in energy consumption and, ultimately, use due to interventions and energy efficiency projects. These relate to energy savings achieved by energy-efficient cogeneration plants, including those using renewable energy sources and those connected to district heating networks.

Considering the mandatory energy integration, Annex 3 of Legislative Decree No 28 of 2011 [31], transposing the RED Directive, identifies obligations to integrate energy from RES in new buildings or buildings subject to major renovation. Besides, since 2018, new thermal energy production plants have to be designed and built to ensure that the 50% of the building's planned hot water, heating, and cooling consumption is covered by RES. Decree-Law No 34 of 30 April 2019 [32] established a contribution for municipalities, up to a maximum of €500 million for 2019, drawn from the Development and Cohesion Fund (FSC), to be used for investments in energy efficiency and sustainable local development. Besides, several Italian National Recovery and Resilience Plan [33] milestones are concerning the use of RES to pursue the 2030 target and double the global rate of energy efficiency improvement (e.g., authorisation procedures for renewable plants simplification and procedures for energy efficiency measures acceleration - unique identification codes M2C2R1.01 and M2C3R1.01, respectively). More than EUR 13 billion strengthen the Ecobonus and Sismabonus for energy efficiency and building safety (unique identification code M2C3I2.01) and EUR 200 million for the promotion of efficient district heating (unique identification code M2C3I3.01). All the reported procedures are linked with the Sustainable Development Goals [34], such as SDG 7, 11, and 13, aiming at ensuring access to affordable, reliable, sustainable and modern energy, make cities and human settlements inclusive, safe, resilient, and take urgent action to combat climate change and its impacts, respectively.

2.2 Standards and regulations multi-level analysis

At European level, the Directive 2000/60/EC [35] of the European Parliament and of the Council of 23 October 2000 establish a framework for community action in the field of water protection policy. One of the purposes of Article 1 is to promote sustainable water use based on their long-term protection, ensuring the progressive reduction of pollution and preventing its further contamination. Furthermore, Article 2 defines the "Groundwater" as the water from the ground's surface in the saturation zone and the term "Water use" as the water services together with any other activity identified under Article 5 and Annex II having a significant impact on the status of water.

By means of the European Green Deal, the European Commission has adopted a series of proposals to transform EU climate, energy, transport and taxation policies to reduce net greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels. Italy intends to promote the European Green New Deal, understood as a green pact with businesses and citizens that sees the environment as the country's economic driver. The Green New Deal expresses itself in different forms and follows different directions, including provisions to transpose the EU Directives implementing the energy and climate package, but also by promoting new and synergistic initiatives, starting with Law No 160 of 27 December 2019 [32]. The recent provision contained in Law No 141 of 12 December 2019 [36], which converted Decree-Law No 111 of 14 October 2019 [37] concerning the transformation of the Interministerial Committee for Economic Planning (CIPE) into the Committee for Sustainable Development (CIPESS), follows the objectives set out in the Green New Deal. Its declared purpose is to foster closer coordination of public policies to pursue the sustainable development objectives set out by Resolution A/70/L.1, which was adopted by the United Nations General Assembly on 25 September 2015 [23].

Considering the Italian context, groundwater protection is governed by national, regional, and local regulations, and these can vary significantly among cities and regions (Figure 2). The Legislative Decree no. 152 3 April 2006 [38] and, in particular, the Title III 'Regulations on soil protection and combating desertification, protection of water against pollution and management of water resources' represents the national regulatory reference. It transposes Framework Directive 2000/60/EC [35] for community action on water and water bodies through the restoration, recovery, and improvement of aquatic ecosystems, the sustainable use of surface and groundwater resources, the implementation of specific measures to reduce discharges and emissions into water bodies and the mitigation of the effects of floods and droughts.

At the basin level, the Po River Basin District Management Plan [39] is the operational tool required by Directive no. 2000/60/EC [35] and implemented, at the national level, by means of the Legislative Decree no. 152/06 [38]. It aims at defining a coherent and sustainable policy plan for the community waters protection, through an integrated approach of the different management and ecological aspects at the river basin district scale.

The paragraphs that follow present the legislative references at the regional, provincial, and consequently, municipal levels. Specifically, the relevant standards to be complained to in a GWHP geothermal plant project were systematically taken into account, considering the in-force regulations for the Piedmont and Lombardy Regions.

2.2.1 GWHPs: The Piedmont Region standards and regulations

In the Piedmont Region, wastewater discharges must be authorized. For a closed-loop geothermal system, with no discharge of wastewater, no authorisation is required, according to Article 124 of Legislative

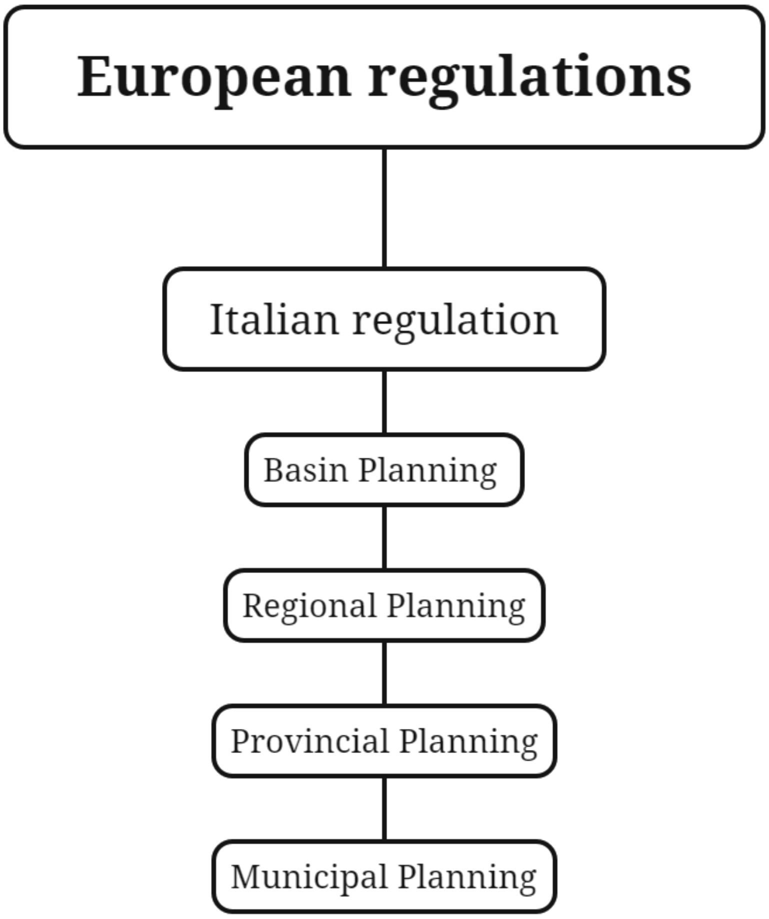

Figure 2 Flowchart depicting the regulatory tools analysis performed at different levels

Decree No. 152/06 [38]. On the other hand, an open-loop is subject to prior authorisation according to Article 124 of Legislative Decree No. 152/06 and in compliance with the sector regulations on water and subsoil protection. The discharge endpoint may be a natural/artificial watercourse or an aquifer. At the regional level, the Water Protection Plan - PTA [40] defines criteria for the prevention and control of groundwater pollution through its continuous monitoring. A good quantitative state of a groundwater is attained when the following two criteria are met: available groundwater resources exceed abstractions in a long-term (multi-year) quantitative balance analysis, and anthropogenic changes in groundwater levels in the groundwater body do not cause damage to surface waters and related ecosystems, even if the water balance does not indicate critical conditions. At the provincial level, the Provincial Territorial Coordination Plan – PTC2 [41] contributes to the achievement of qualitative and quantitative levels for groundwater and surface water, through an articulated strategy of behaviours aimed at controlling point and diffuse pollution. It ensures the maintenance of a minimum level of naturalness of the water bodies themselves in the areas surrounding the water bodies identified by the PTA, and introduces rules/guidelines of an urbanistic nature in the General Town Planning (PRG) in order to limit the spread of the phenomenon of soil sealing. At the municipal level, the Metropolitan General Territorial Plan - PTGM [42] promotes the protection and sustainable use of water resources as a heritage and common right of humanity and all living species, an essential public good for the environment and for the economic and social development. The deep aquifer system needs to be protected and preserved, given its priority use for human consumption.

Article 29 of the Plan Regulations of the PTA of Piedmont Region provides that, by way of derogation from the prohibition on discharging into groundwater and subsoil according to Article 104 of Legislative Decree No. 152/2006 [38], the competent authority may authorise discharges into the same aquifer, only in the absence of technically and economically feasible discharge or reuse alternatives. Besides, paragraph 2 of the same Article 29 describes that such authorisations are issued after an investigation aimed at verifying: (a) the geometry and hydrochemical characteristics of the water body receptor; (b) the modifications induced on the morphology of the piezometric surface; (c) changes in the chemistry of the aquifer concerned by the assessment of effects on the thermal and hydrochemical status; (d) the overlapping effect of any other geothermal plants insisting on groundwater body in the investigation area.

Presidential Decree No. 59 of 13 March 2013 [43] introduced the Single Environmental Authorisation (AUA), with the goal of streamlining requirements for small and medium-sized enterprises, as well as all facilities not subject to the Integrated Environmental Authorization (AIA). [38]: it integrates into a single document the environmental authorisations required by the sector of legislation which the company should have previously obtained separately. The application form must be submitted to the SUAP (Single Desk for Productive Activities) through a specific online platform. In detail, the Piedmont Region has required that the technical documentation would be different, according to the discharge capacity assumed in the project: 1) small installations, discharge up to 2 l/s; 2) medium installations, discharge between 2 l/s and 10 l/s; 3) large installations, discharge exceeding 10 l/s. In the latter, the technical documentation must include:

- report demonstrating the absence of reuse or discharge alternatives;
- cartographies/plans of the settlement and the project;
- technical report and graphic diagram of the plant circuit, providing the maximum temperature of the wastewater discharge, and ensuring the absence of interference between the discharge and neighbouring building structures;
- the implementation of at least one control piezometer downstream of the discharge;
- technical report on the characteristics of the water table;
- prediction of the evolution over time of the heat/cold plume propagation in the aquifer, simulating the amplitude, duration, and mode of propagation.

The use of predictive models for at least 3 years of the geothermal plant's activity is required but not strictly regulated: the performed numerical simulations should consider the boundary conditions, the aquifer's natural conditions, the parameters of the geothermal plant and operating regimes (monthly average temperature and flow rate). In addition, the absence of interference between the extraction and discharge wells and the lack of overlap with other neighbouring facilities should be verified.

For obtaining authorisation for the discharge of plants, it is necessary to install, on both the intake and discharge of water flow rate, temperature and volume measuring and recording instruments which must have the technical characteristics complying with articles no. 10, 12, and 13 of Regional Presidential Decree no. 7/R of 25/06/2007 [44]. Besides, it is necessary also to equip a monitoring piezometer downstream of the well with a multi-parameter probe with continuous measurements of groundwater level, temperature, and electrical conductivity and create an appropriate record. An annual report that presents the results of monitoring with graphs and/or tables, showing trends over time and the thermal plume revised, based on the monitored data must be prepared and submitted.

2.2.2 GWHPs: The Lombardy Region standards and regulations

Considering the Lombardy Region, the Water Protection and Use Plan - PTUA [45] represents an instrument that identifies the measures and interventions required for ensuring the protection and qualitative safeguard of the regional water bodies. At a provincial level, the Provincial Coordination

Territorial Plan - PTCP [46], approved by Provincial Council Resolution No. 40 of 22 April 2004, defines the objectives of sustainable development of the territory, directs socio-economic planning, and has the value of an environmental landscape plan. Precisely, the PTCP aims at assuring the compatibility between the natural and anthropic environmental systems. At the municipal level, the reference is represented by the Territorial Government Plan - PGT [47] with its several technical tables inside, including geological, hydrogeological, and seismic feasibility.

Specifically, the maximum and average flow rates of the abstraction wells for the plant are taken into account. For a geothermal plant with a maximum flow rate below 50 l/s, the standard procedure is employed. This involves submitting distinct concession applications for derivations and an Authorization for Use of Public Waters (AUA) for the designated reinjection wells. The Metropolitan City Water Resources sector oversees the concession application, and different approval timelines are applicable for each application. Besides, in the case of a maximum flow rate, greater than 50 l/s but less than 100 l/s, an Environmental Impact Assessment (VIA) [48] must be submitted before applying for the ordinary procedure. They are managed by the Metropolitan City Water Resources sector. On the other hand, in the case of a maximum flow rate greater than 100 l/s and an average flow rate of fewer than 100 l/s, a single application is submitted through the Regional Single Authorisation Measure - Environmental Impact Assessment (PAUR-VIA), which brings together all the applications concerning wells and is managed by the Metropolitan City - noise and energy quality sector. In the last case (maximum flow rate greater than 100 l/s and an average flow rate greater than 100 l/s), it is, therefore, necessary to submit the Regional Single Authorisation Measure (PAUR), which collects all the well applications but, in this case, is managed by the Lombardy Region. The technical documentation must include:

- definition of the environmental status of groundwater bodies, which can be obtained through the ERA (Environmental Risk Assessment) method as indicated by the PdGPo, modified by STA Directorial Decree No. 293 of 25 May 2017 [49];
- cartographies/plans of the settlement and the project;
- report containing piezometric trend analysis to verify the effectiveness of the measures taken to maintain or achieve ‘good’ quantitative status of groundwater bodies;
- technical reports for the recognition of areas subject to protection and soil conservation;
- geological, hydrogeological and seismic feasibility reports to which the project area belongs;
- technical report on the characteristics of the geothermal plants, such as supply methods, water demand and water discharge;

- report on the simulation through numerical predictive models of the piezometric interference of the geothermal plant and the influence of the thermal plume on the aquifer.

The Environmental Risk Assessment (ERA) method, utilized for assessing the environmental status of groundwater bodies as reported above, is a systematic approach employed to scrutinize and evaluate potential environmental risks linked to specific human activities. This methodological framework involves a comprehensive examination of pressures exerted on a natural system, with the primary goal of understanding their potential impacts on the environment. Within the specific domain of water derivations, the ERA method, is centered on the meticulous characterization of pressures deemed "potentially significant" for water bodies. The goal is to determine whether these pressures could compromise the attainment or maintenance of environmental quality objectives set by EU regulatory directives 2000/60/EC [35]. The procedural trajectory of the ERA involves a detailed assessment of the specific impacts stemming from the identified pressures. Ultimately, the ERA method facilitates a rigorous and comprehensive evaluation of the environmental risks inherent in water derivations, whether in isolation or in conjunction with other influencing factors. The resultant assessment allocates interventions to distinct environmental risk categories such as "Attraction," "Repulsion," or "Exclusion," furnishing a structured framework for the elucidation and management of potential impacts on water bodies.

2.3 Case study 1: Città di Torino hydrogeological setting

The Piedmont Region is characterised by several morphological features and geological structures: the Alps and Apennines Mountain chains, Monferrato and Langhe hills, the end-moraine systems and fluvio-glacial or alluvial fan at the outlet of major Alpine and Apenninic valleys, major glacial lakes in the northern part of the region and the wide alluvial plains of Po River [50].

Precisely, the Turin City is located in the Turin plain that extends from the Rivoli-Avigliana Morainic Amphitheatre (RAMA) on its western extreme to Turin Hill on its eastern border (Figure 3). The geological succession is composed by an oldest unit (Unit 3-Miocene), constituted by conglomerates, sandstones and marls typical of the molassic sequence belonging to the Piemonte Tertiary Basin. The upper part is locally characterized by the presence of evaporites belonging to the Messinian Gessoso-solfifera Formation. Unit 3 is stratigraphically overlapped by the subsequent Unit 2 (Pliocene) (surface α) or truncated by the main erosional quaternary surface (γ) and therefore directly in contact with the upper outwash deposits (Unit 1-Quaternary). The youngest unit (Unit 1-Quaternary) is constituted by fluvial and fluvioglacial coarse gravels with subordinate sands and silts (locally cemented) derived from alluvial fans aggraded by the alpine rivers down-streaming towards the east and has an average thickness of about 30-40 m with a general trend decreasing from W to E and N [51].

The hydrogeological setting is strongly influenced by the presence of the Rivoli-Avigliana Morainic Amphitheatre (RAMA). The buried lithotypes of Unit 3 below Units 1 and 2 (Figure 4) represent the bottom impermeable layer for the unconfined groundwater regional down-flowing towards east mainly developed in the quaternary deposits (Unit 1). Unit 1 represents an important unconfined highly productive aquifer hydraulically connected to the main surface water drainage network (Sangone, Dora Riparia, Stura di Lanzo and Po rivers). The permeability can reach high values ($10^{-3} \div 10^{-4}$ ms^{-1}) depending on the local sediment granulometry. The potentiometric surface shows generally a W-to-E gradient, ranging from 0.6-1.2% (mean 0.9%). Unit 2 hosts a highly productive multi-aquifer system intensively pumped for human consumption. Due to the lithological composition and the tectonic setting, Unit 3 hosts confined aquifers scarcely productive. In the hilly sector they are exploited mainly for domestic uses [51].

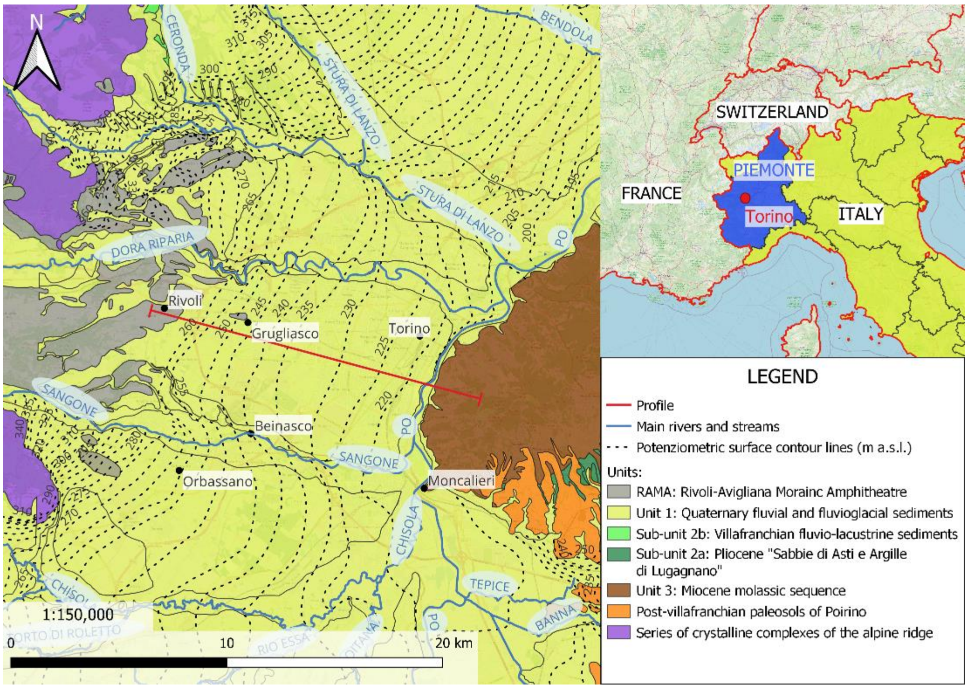

Figure 3 Hydrogeological map of the Turin area (modified from [51])

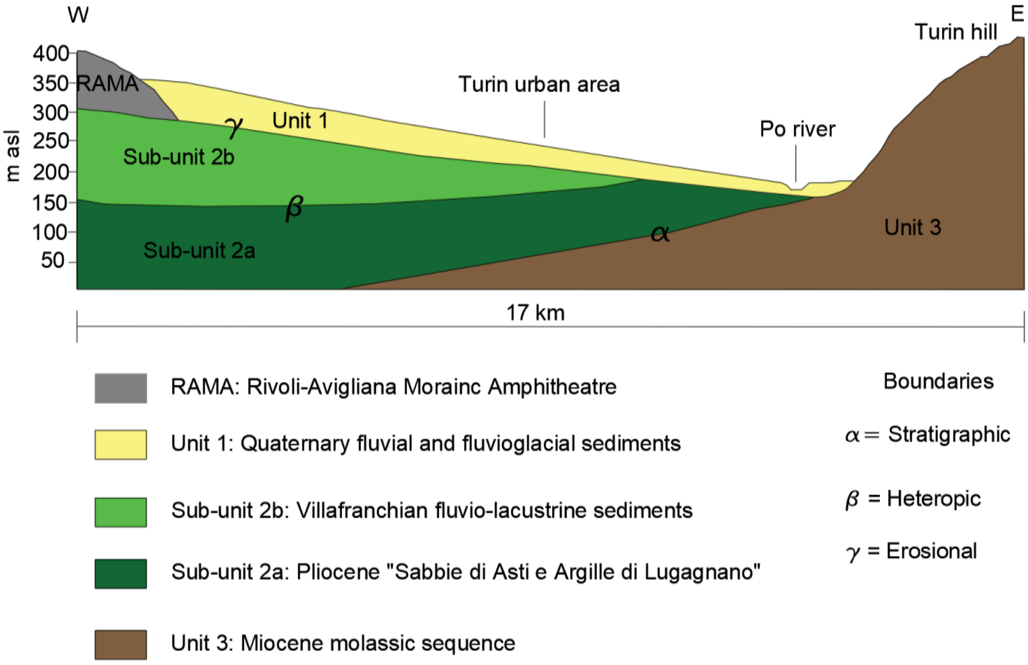

Figure 4 Cross-section and stratigraphic relationships (modified from [51])

Due to its hydrogeological characteristics, the shallow aquifer hosted in Unit 1 represents a good resource for allowing the construction of geothermal open-loop plants.

2.4 Case study 2: Città di Milano hydrogeological setting

From a geological point of view, the Lombardy Region can be divided into three main zones: the Alpine belt in the north, the Po Plain in the center, and the Oltrepò Pavese in the souther part. The Po Plain is situated between the Alps and the Apennines thrust belts, evolved as a foreland basin of the Apennines from the Messinian [52] while as a distal ramp of the Apennine foreland basin during the Pliocene [53]. Milan city lies within the fluvioglacial Riss and fluvial Wurm deposits of the Upper Pleistocene. This area is characterised by the presence of two regional unconformities that have led to the definition of three subsoil units: supersintema Padano (PD), supersintema Lombardo Inferiore (LI) and supersintema Lombardo Superiore (LS). These units sealed the Miocene bedrock, and the upper unit (LS) consists of coarse and medium gravel, clast supported and locally cemented, with subordinate layers of medium and coarse sands and gravelly sands.

Fine lithologies, such as silts and clayey silts may be intermittently encountered, and their lateral continuity is often reduced, particularly in association with the upper unit (LS) (Figure 5).

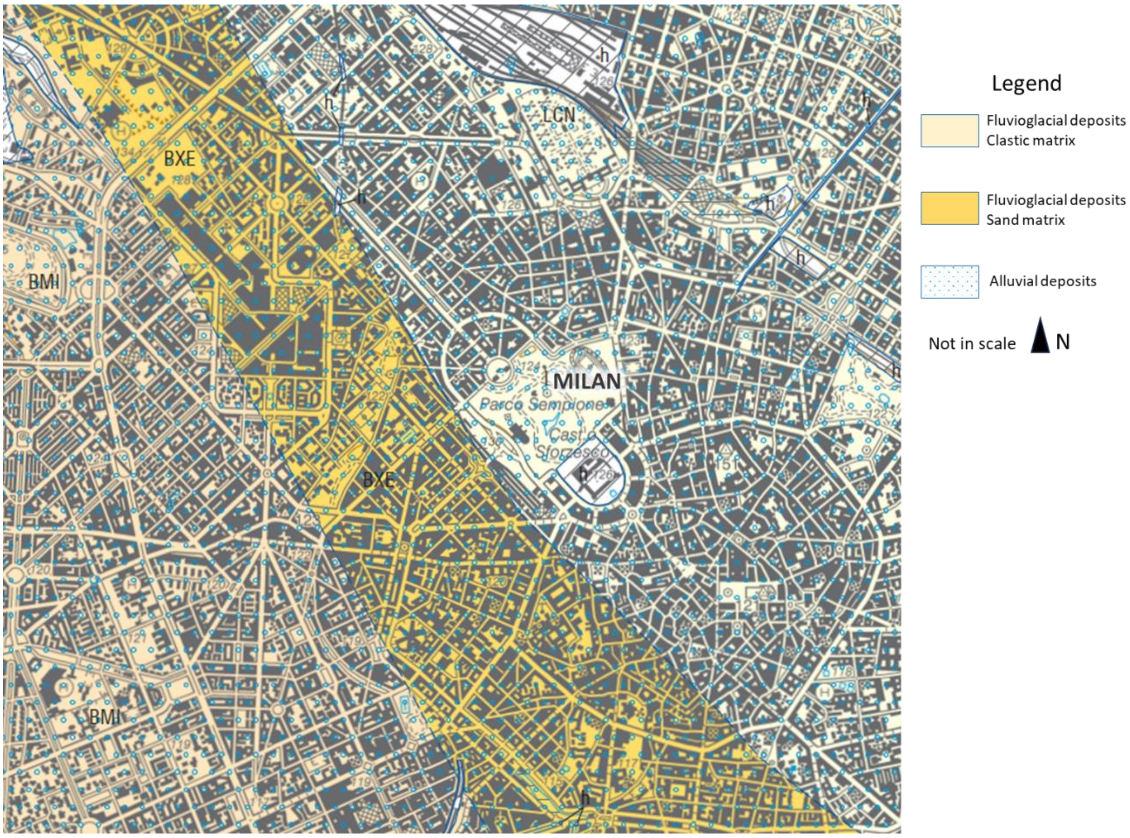

Figure 5 Geological Map of Milan (from Sheet 118, [54])

Considering the lithological characteristics, deduced from the wells' stratigraphies in the area, three main hydrostratigraphic units can be recognised, from shallowest to deepest, the Aquifer Group A, B, and C [55,56]: the Aquifer Group A, with an average thickness of 20-50 m from ground level, is composed mainly of highly permeable coarse lithologies (pebbles, gravels, and sands), with subordinate lenticular intercalations of sandy silts and yellow/brown clays. This unit contains the first, most vulnerable aquifer, representing the exploitable resource for geothermal open-loop systems diffusion. The A Aquifer is separated by a clayey silty aquitard (2–5m thick) from the B Aquifer (semi-confined), with an average thickness of 50-100 m composed of sands and sandy gravels. The deep confined (Aquifer C) consists of overlapping silty-clayey and fine sand units. In Figure 8 there is a cross-section of a group aquifer representation [56], that shows the three different aquifers (A, B and C; Figure 6).

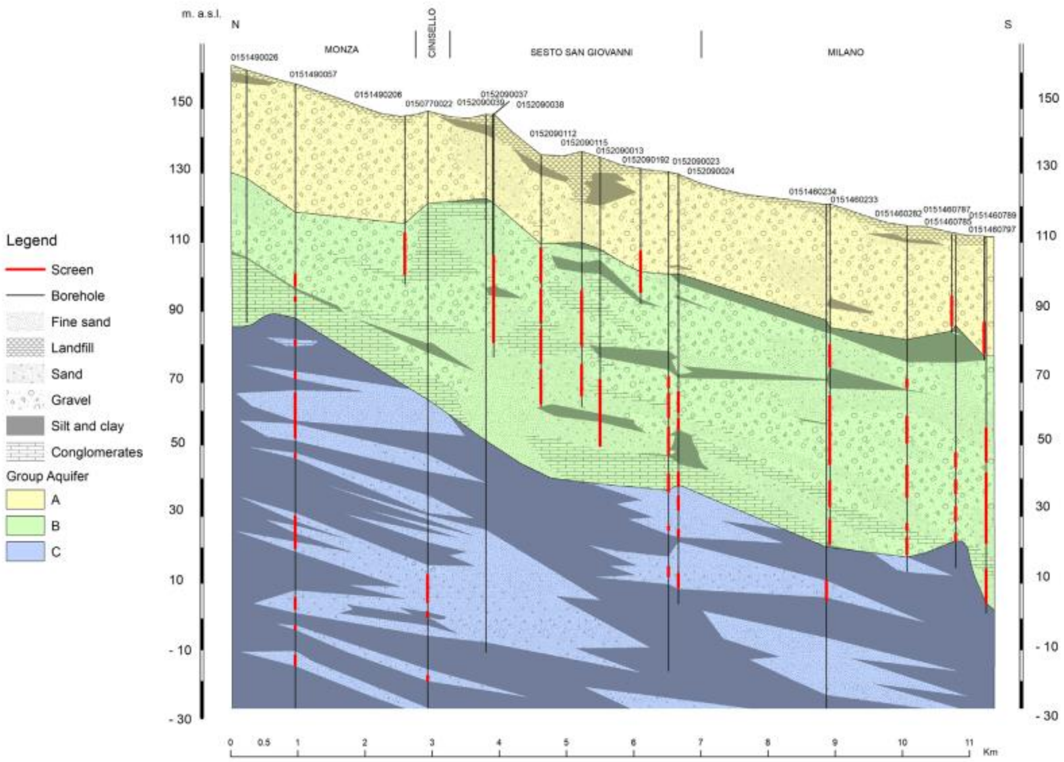

Figure 6 Hydrogeological cross-section of Milan area [56]

3. Results and Discussion

The regional and urban planning standards and regulations for a new GWHP installation with which Piedmont and Lombardy Regions are equipped were proposed and summarised through a schematic and multi-level analysis approach. The performed comparison between the authorisation's regulations for a GWHP in Turin and Milan cities areas, described in chapters 2.2.1 and 2.2.2 and proposed in Figure 7, allowed depicting analogies and differences among existing planning tools. In-force regulations of the two cities interpret and refer to national legislation differently, thus resulting in a different systems diffusion rate and authorisation approval time. At an urban scale authorization processes and regulations present differences, despite a common hydrogeological setting for the area of the city of Turin and Milan, with the presence of a very productive shallow unconfined aquifer, contained in highly permeable coarse lithologies (pebbles, gravels, and sands) of alluvial origin (see chapters 2.3 and 2.4). It is not incorrect to identify in these differences the causes of the different diffusion rate of the GWHPs in the two analysed different areas.

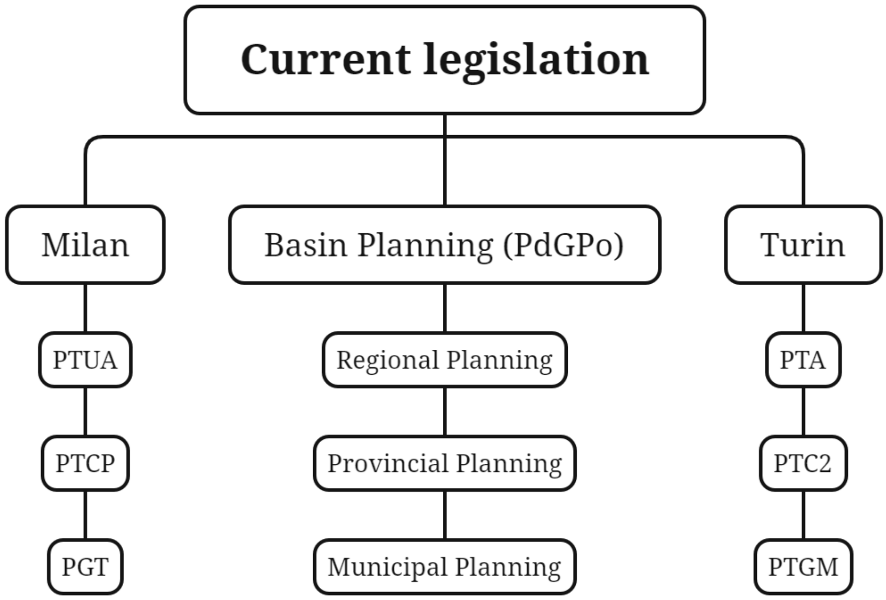

Figure 7 Comparison between the described planning instruments for the Piedmont and Lombardy Regions. Acronyms reported are defined in Chapters 2.2.1 (Piedmont Region) and 2.2.2 (Lombardy Region).

In the Piedmont Region, approval is required for wastewater discharge values. In contrast, the Lombardy Region considers both maximum and average flow rates from extraction wells. The defined wastewater discharge capacity classes for the Piedmont Region are: 1) small installations, discharge up to 2 l/s; 2) medium installations, discharge between 2 l/s and 10 l/s; 3) large installations, discharge exceeding 10 l/s. Conversely, for Lombardy Region: maximum abstraction flow rate below 50 l/s, maximum flow rate greater than 50 l/s but less than 100 l/s, maximum flow rate greater than 100 l/s and an average flow rate of less than 100 l/s.

Analogies are evident in the technical documentation required to accompany particular authorization requests. According to Regional Environmental Energy Plan [57] geothermal heat pumps in the Piedmont Region have rapidly increased from 2005 to 2015. A further development is expected in the coming years. As reported in chapter 2.2.1, any new open-loop plant is subject to prior authorisation according to Article 124 of Legislative Decree No. 152/06 and in compliance with the sector regulations on water and subsoil protection. Authorisations are issued after an investigation aimed at verifying (paragraph 2 - Article 29): (a) the geometry and hydrochemical characteristics of the water body receptor; (b) the modifications induced on the morphology of the piezometric surface; (c) changes in the chemistry of the aquifer concerned by the assessment of effects on the thermal and hydrochemical status; (d) the overlapping effect of any other geothermal plants insisting on groundwater body in the investigation area. The implementation of at least one control piezometer downstream of the discharge and a preliminary identification of an attention limit for the temperature of the discharged effluent and management discipline in case of exceeding it (between 20-22 °C summer season; 7-8 °C winter season) are mandatory. The reinjection of the thermally disturbed quantity of water into the exploited aquifer, associated with each GWHP is potentially able to cause a significant thermal impact on the aquifer: the technical requests associated with the authorization process, for both Piedmont and Lombardy Regions, have the objective of monitoring and predicting, thus limiting the impact of the alteration produced. Moreover, at the local level, the climate component, together with the recharge conditions and anthropogenic impacts (e.g., underground infrastructure networks), can have an important influence on the shallow aquifer temperatures. Despite the soil consumption rate in Turin corresponds to 65% [42], the current thermal trend of the shallow aquifer in the Turin area (i.e., about 20 m deep with respect to the surface of the ground floor) shows a relatively stable temperature. As reported in [58], where the authors performed an analysis of the GroundWater Temperature (GWT) over a period of 10 years (from 2010 to 2019), the increasing trend in GWT basically reflects the increase in air temperature. Seasonal variations affect only the superficial part of the aquifer. Anthropogenic impacts on GWT are not significant. This aspect, together with the high productivity of the surface aquifer within Unit 1 (see chapter 2.3), contributes to the creation of favourable conditions for the large-scale use of groundwater heat pumps (GWHP). Therefore, at present, the installation of GWHPs is limited: Fig. 8a shows the wells' diffusion of the Turin city urban area. However, the nature of the data available for the Piedmont Region (i.e., the location of a well associated with an authorization procedure) does not allow professionals to easily identify drilling and extractions built for geothermal purposes. More precisely, considering the available information resulting from consultation of different AUA practices, 44 geothermal plants have been installed in the Turin Province area ([59]; data updated to June 2023) (Figure 8b). No urban census of geothermal wells is available for Turin city: the data proposed in Fig. 8b were gathered by analysing the single environmental authorization (AUA) for extraction wells only, available on the website of the Metropolitan City of Turin [59]. These data were integrated with those available on the ARPA Piedmont website (Figure 8a), thus including injection wells in the map. Conversely, for the city of Milan it is possible to automatically discretize the geothermal plants among all the drilled wells, through the analysis of available data accessing on the [60] (Figures 9a, 9b).

In Milan province, more than 209 geothermal plants and associated 796 shallow geothermal wells are present (data updated to June 11, 2021), with a heating capacity of over 4600 KW and a cooling capacity of over 4000 KW [60]. According to what reported in Figure 10, over 86% of geothermal plants are used for residential purposes. In addition, the city area hosts six underground metro lines, and many deep infrastructures' foundations. Anthropogenic and environmental impacts of underground infrastructure networks, land use rates and GWHPs, respectively, have caused variation on the shallow aquifer's temperatures. In their work, [61] described the change in thermal energy stored in the Milan shallow groundwater bodies due to changes in natural and anthropogenic factors such as climate, city size and shallow geothermal installations. Over time, the groundwater thermal regime in Milan urban areas has been governed by the complex superimposition in time and space of positive and negative heat flows from many natural and anthropogenic sources: more than 3°C difference between the surface aquifer temperature was measured in the centre of Milan and the respective rural areas around the city and a warming trend of +0.4 °C/year observed in the city centre.

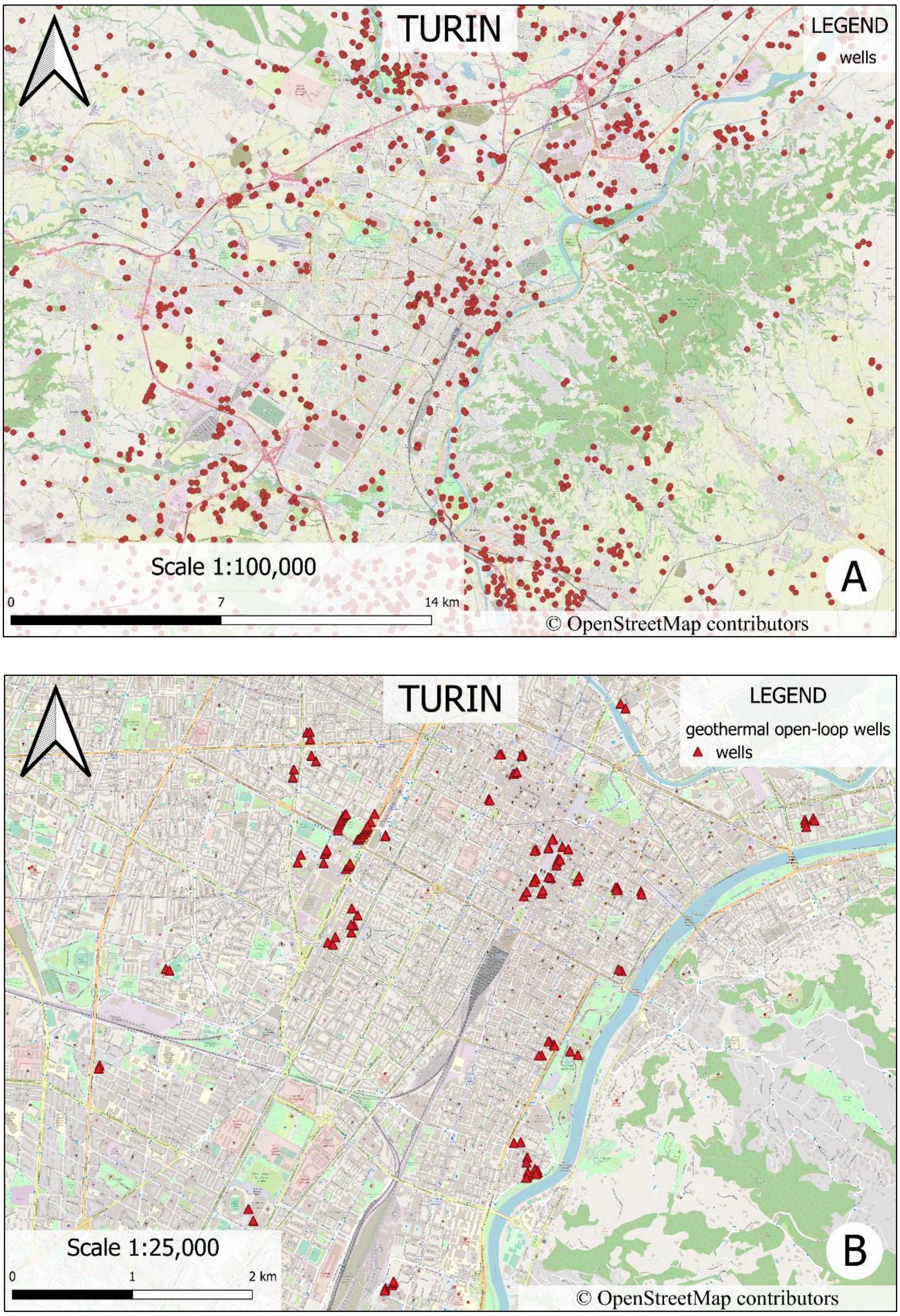

Figure 8 a) Wells in Turin municipality [62]; b) Geothermal open-loop wells in Turin municipality

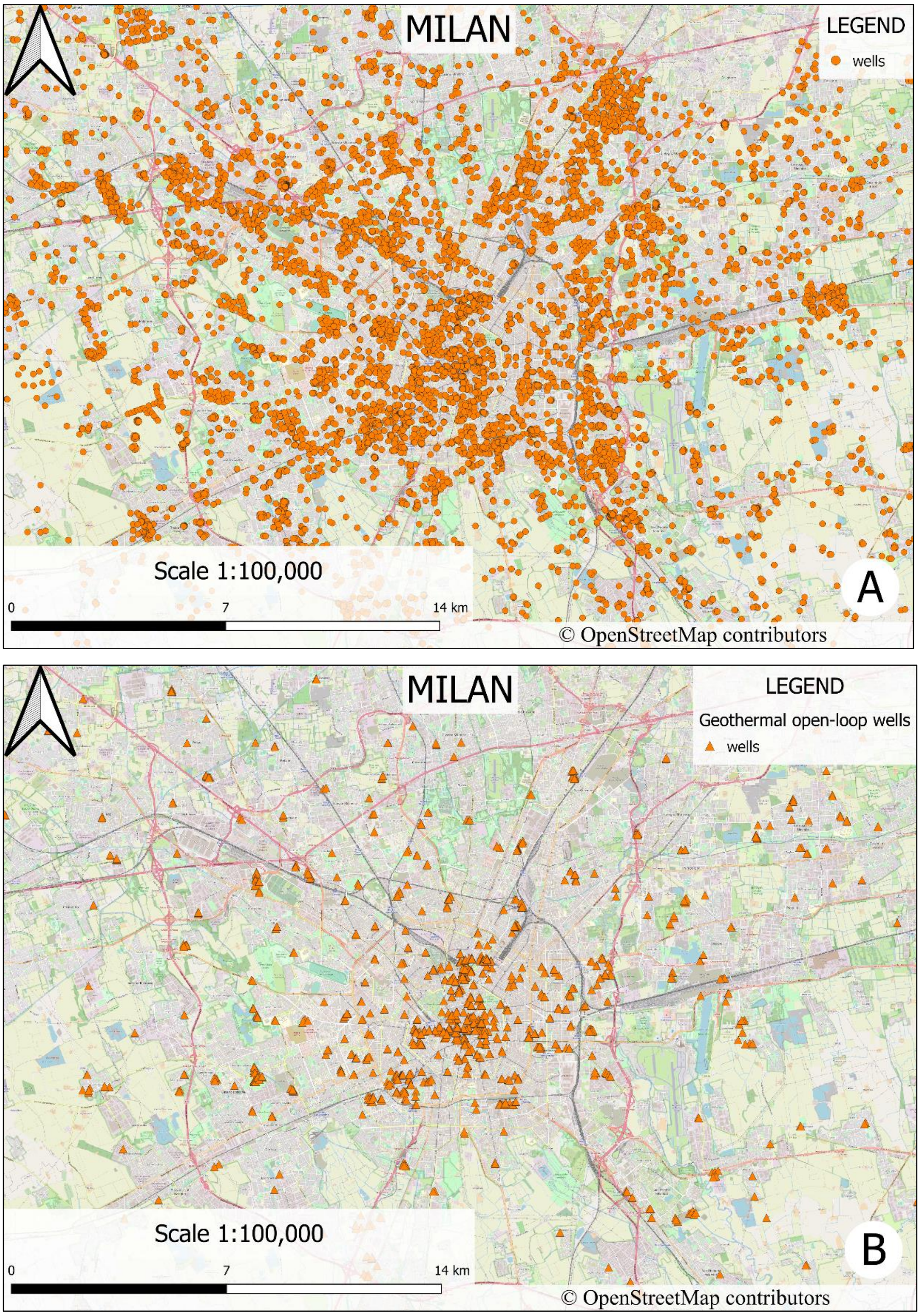

Figure 9 a) Wells in Milan municipality [60]; b) Geothermal open-loop wells in Milan municipality (data from [60])

Thus, in urbanised areas such as Milan city, intensively exploited for direct geothermal energy purposes, the installation of GWHPs should be accompanied by instruments and regulatory approaches aimed at monitoring, forecasting and limiting the additional thermal impacts caused by installations on the aquifer.

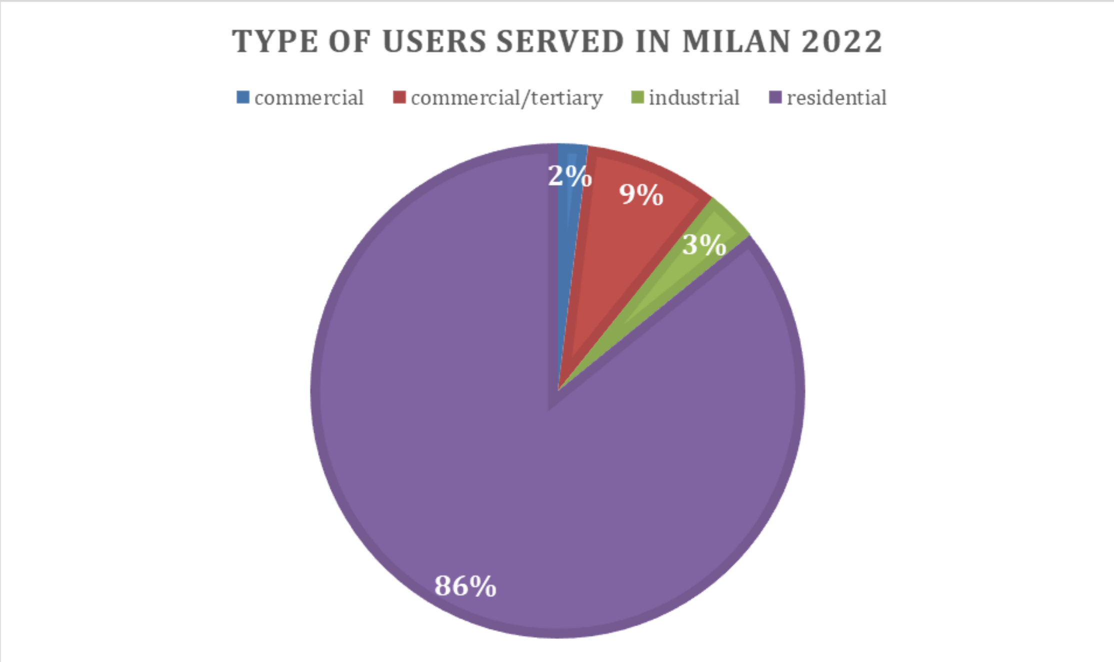

Figure 10 Type of users served in Milan (data from [63])

4. Conclusions

Existing buildings in Italian urban areas account for a considerable proportion of the demand for low temperature heating and cooling that can be sustainably supplied by GWHP systems. Currently, thermal use through geothermal heat pumps is difficult to quantify in Italian cities. Only a very few local authorities have a plant register (like Lombardy Region). The lack of a consistent regulatory framework at a regional scale leads to a fragmentation in the quality of available data, frequently complicating the comparison of various urban environments. The proposed approach involved conducting a multi-level analysis of the standards and regulations in urban and regional planning that the Piedmont and Lombardy Regions have in place. Similarity in the hydrogeological setting and, consequently, in the exploitable resource (i.e., shallow unconfined aquifer) and differences in 1) authorization requests for extraction/abstraction operations, 2) wells and GWHPs diffusion data in both Turin and Milan urban areas were underlined. In both urban contexts, over 50% of the installed systems are located in central and historic city centres. The higher observed diffusion rate for the urban context of the city of Milan (i.e., 209 geothermal plants), in addition to being a result of favourable socio-economic conditions, is linked to more streamlined authorization procedures in terms of timing and types of authorizations required based on the size of the plant. In order to promote a rapid but sustainable diffusion in the medium and long-term of open-loop geothermal solutions in densely urbanised contexts, urban planning instruments must pursue the following aim: to ensure adequate long-term protection of the groundwater bodies, through an understanding of the subsoil in the decision-making process. Working on national-scale regulatory tools and standards is the objective that authorities must pursue.

The analysis approach proposed in this paper and used to analyse the in-force legislation in the Piedmont and Lombardy, from an international perspective down to the municipal level, can be replicated for other Italian regions, highlighting the critical points that obstacle the diffusion on a large scale of the available renewable alternatives (i.e., GWHPs) for heating and cooling buildings. The results of the multilevel analysis performed is proposed as a guide to allow professionals to understand the various regulatory processes that guide the authorization methods of new geothermal plants in both contexts. As partially highlighted in the work, the hydrogeological potential of some cities in the Po Valley (e.g., Turin city) is not negligible: it could be further consciously exploiting underground resources that would otherwise be wasted. This can be done in a sustainable way, properly estimating the nature of the thermal impact through its numerical simulation. Efficient management of authorization applications, together with an optimal use of the available economic incentives, can represent the key to supporting the diffusion of the geothermal technologies in densely populated areas, partially countering the achievement of the medium and long-term sustainable development objectives.

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