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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

33 poverty, are increasingly needed. As part of the initiative above-reported, cities have undertaken to meet
34 and exceed European targets in terms of CO₂ emissions reduction of at least 40% by 2030, demonstrating
35 a level of ambition often higher than the national level of the respective countries [2].

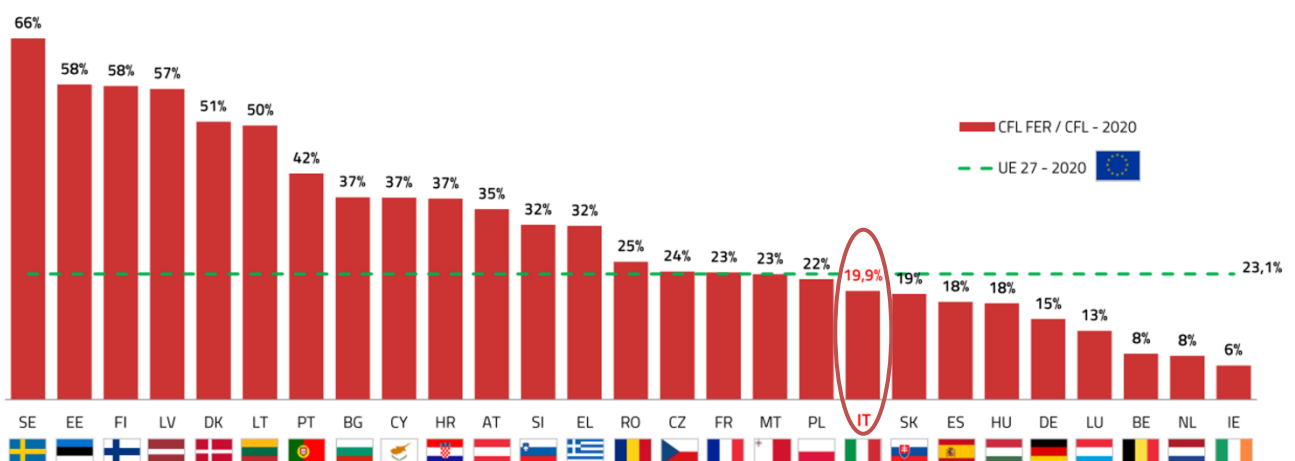
36 At a national scale, Italian urban areas turn out to be characterised by centuries-old infrastructure: 35%
37 of the Italian buildings stock is made up of buildings built before 1970 [3] and about 75% is thermally
38 inefficient [4]. In this scenario, a significant obstacle lies in the gradual reduction of total energy
39 requirements and the correlated greenhouse gas emissions by incorporating existing renewable energy
40 solutions into buildings. [5–8]. Among available renewable energy sources (RES), shallow geothermal
41 energy is a promising low-carbon option for fulfilling the energy requirements of urban buildings,
42 particularly in temperate regions [9,10]. In closed-loop ground-source heat pump systems (GSHPs)
43 exchange heat with the subsoil through one, or multiple borehole heat exchangers (BHEs) installed at
44 depths of up to 200 m [11–13]. Conversely, in an open-loop groundwater heat pump systems (GWHPs)
45 groundwater is extracted from an aquifer or similar source and conveyed to the heat pump, where it
46 transfers its heat through the evaporator. Subsequently, the water is either reintroduced into the ground
47 or released at the surface [14,15]. Despite their not widespread application at the national level, GWHPs
48 presently stand out as highly appropriate technologies for heating and cooling buildings. As described in
49 [16], the performances of GWHPs strongly depend on the heating and cooling required thermal loads,
50 heat pump design characteristics (e.g., compressor efficiency and heat exchanger configuration), control
51 strategies, and aquifer characteristics (e.g., groundwater temperature, thermal and hydraulic conductivity
52 of geological formations). Besides, depending on the use mode (heating or cooling), energy can be
53 extracted or injected into the shallow aquifer. The reinjection of a thermally perturbed amount of water
54 in the exploited aquifer has the potential to cause, even in the short term, significant environmental
55 impacts associated with the origin of a thermally affected zone (TAZ). Therefore, identifying alternatives
56 to discharge in the shallow aquifer (i.e., surface rivers), especially for densely urbanised areas, is often
57 necessary [17,18]. Because of the above-described environmental limit, urban and regional policies for
58 encouraging the diffusion of open-loop systems in urban areas cannot be disregarded the knowledge
59 about geological and hydrogeological settings. Ensuring that the increase in the GWHPs diffusion rate is
60 sustainable in the medium and long period, in terms of thermal impact on groundwater resources, is
61 essential. Therefore, the introduction of new planning standards and regulations must simultaneously
62 pursue a dual objective: 1) to allow for rapid diffusion of open-loop groundwater heat pumps (GWHPs)
63 and 2) to ensure adequate medium and long-term aquifer's protection, by taking into account the
64 hydrogeological properties of the subsoil during the decision-making and authorization process. In the

65 described process, the development of a numerical simulation model plays an important role, also in
 66 forecasting the TAZ's propagation modalities over time [19–21].
 67 A comprehensive and multi-level analysis of the urban and regional planning standards and regulations
 68 with which some Italian regions (Piedmont and Lombardy Region) are equipped is proposed in this paper.
 69 In detail, the main regulatory references to which a geothermal project must comply concerning the in-
 70 force national, regional, and municipal regulations (i.e., geothermal wells drilling authorization requests
 71 and plant final testing operations) were taken into consideration and summarised through a schematic
 72 approach. The various regulatory instruments analysed pursuing the above-described objectives were
 73 tested, also performing an analysis of the diffusion rates of GWHPs in two different contexts at an urban
 74 scale: the comparison between the cities of Turin and Milan represents a useful tool for researchers and
 75 professionals for properly depicting and identifying the peculiarities and criticalities of both
 76 hydrogeological contexts in terms of allowing GWHPs diffusion.

77 2. Materials and Methods

78 2.1 Renewable Energy Sources: Italian development framework

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



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

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

88 1300 MW_{th}, with a corresponding total energy use of 9668 TJ/yr. The main sector of utilization is the space
89 heating of the buildings, which accounts for 41% and 49% in terms of installed capacity and energy use,
90 respectively [26]. In 2021, there were 226 active installations in Italy for the exploitation of direct
91 geothermal energy for the sole heat production purposes. These are, in most cases, individual heating
92 and thermal plants [27].

93 The heating sector is expected to play a major role in achieving the Italian RES medium to long-term
94 targets. A decisive technological shift towards increasingly new RES solutions is required: the diffusion of
95 open and closed-loop heat pumps is a key instrument to decarbonise existing thermal energy systems.
96 At present, it is challenging to accurately measure the distribution of geothermal heat pump systems in
97 Italy. To date, no national census is available for consultation, and only a very few local authorities have
98 a plant register. Moreover, the absence of a univocal regulatory framework results in a high fragmentation
99 of the few available data, difficult to compare because they refer to different systems (in some cases the
100 data refer to water-based heat pumps; in other cases, to vertical closed-loop systems or any closed-loop
101 geothermal configurations).

102 A national restructuring of regulations concerning the exploration and exploitation of geothermal
103 resources was proposed through the Legislative Decree no. 22 of February 11, 2010 [28]. According to
104 Article 10 of the Legislative Decree no. 22 small local uses of geothermal heat are those that
105 simultaneously meet the following conditions: a) Allow the implementation of systems with thermal
106 power less than 2 MW, obtainable from geothermal fluid at the conventional temperature of effluents of
107 15 degrees Celsius; b) Are obtained through the drilling of wells up to 400 meters for the exploration,
108 extraction, and use of geothermal fluids or hot waters, including those flowing from springs, for a total
109 thermal power not exceeding 2,000 kW. Small local uses of geothermal heat also include those carried
110 out through the installation of geothermal probes that exchange heat with the subsurface without
111 withdrawing and reinjecting hot water or geothermal fluids into the subsurface. In connection with this
112 last type of local use, the Legislative Decree issued on September 30, 2022 [29] represents the first
113 effective tool for formalizing and regulating the construction of closed-loop geothermal plants. National
114 guidelines governing the establishment of facilities dedicated to heat production from above-mentioned
115 geothermal systems, specifically for building heating and air conditioning, are outlined here. Such a
116 legislative instrument is still absent for GWHPs. The Regions continue to be the competent authorities for
117 administrative tasks, including supervision, related to the small local applications of geothermal heat
118 through GWHPs.

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

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

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

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

151 modern energy, make cities and human settlements inclusive, safe, resilient, and take urgent action to
152 combat climate change and its impacts, respectively.

153 **2.2 Standards and regulations multi-level analysis**

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

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

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

181 reduce discharges and emissions into water bodies and the mitigation of the effects of floods and
182 droughts.

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

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

192 **2.2.1 GWHPs: The Piedmont Region standards and regulations**

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

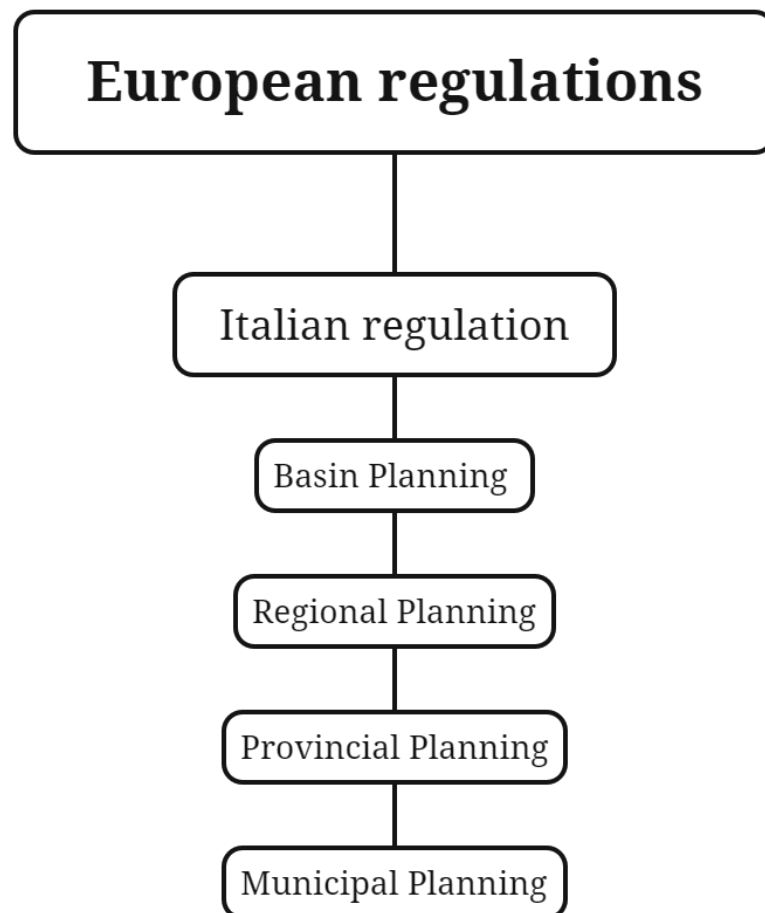


Figure 2 Flowchart depicting the regulatory tools analysis performed at different levels

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

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

223 Presidential Decree No. 59 of 13 March 2013 [43] introduced the Single Environmental Authorisation
224 (AUA), with the goal of streamlining requirements for small and medium-sized enterprises, as well as all
225 facilities not subject to the Integrated Environmental Authorization (AIA). [38]: it integrates into a single
226 document the environmental authorisations required by the sector of legislation which the company

227 should have previously obtained separately. The application form must be submitted to the SUAP (Single
228 Desk for Productive Activities) through a specific online platform. In detail, the Piedmont Region has
229 required that the technical documentation would be different, according to the discharge capacity
230 assumed in the project: 1) small installations, discharge up to 2 l/s; 2) medium installations, discharge
231 between 2 l/s and 10 l/s; 3) large installations, discharge exceeding 10 l/s. In the latter, the technical
232 documentation must include:

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

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

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

255 **2.2.2 GWHPs: The Lombardy Region standards and regulations**

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

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

265 Specifically, the maximum and average flow rates of the abstraction wells for the plant are taken into
266 account. For a geothermal plant with a maximum flow rate below 50 l/s, the standard procedure is
267 employed. This involves submitting distinct concession applications for derivations and an Authorization
268 for Use of Public Waters (AUA) for the designated reinjection wells. The Metropolitan City Water
269 Resources sector oversees the concession application, and different approval timelines are applicable for
270 each application. Besides, in the case of a maximum flow rate, greater than 50 l/s but less than 100 l/s, an
271 Environmental Impact Assessment (VIA) [48] must be submitted before applying for the ordinary
272 procedure. They are managed by the Metropolitan City Water Resources sector. On the other hand, in
273 the case of a maximum flow rate greater than 100 l/s and an average flow rate of fewer than 100 l/s, a
274 single application is submitted through the Regional Single Authorisation Measure - Environmental Impact
275 Assessment (PAUR-VIA), which brings together all the applications concerning wells and is managed by
276 the Metropolitan City - noise and energy quality sector. In the last case (maximum flow rate greater than
277 100 l/s and an average flow rate greater than 100 l/s), it is, therefore, necessary to submit the Regional
278 Single Authorisation Measure (PAUR), which collects all the well applications but, in this case, is managed
279 by the Lombardy Region. The technical documentation must include:

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

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

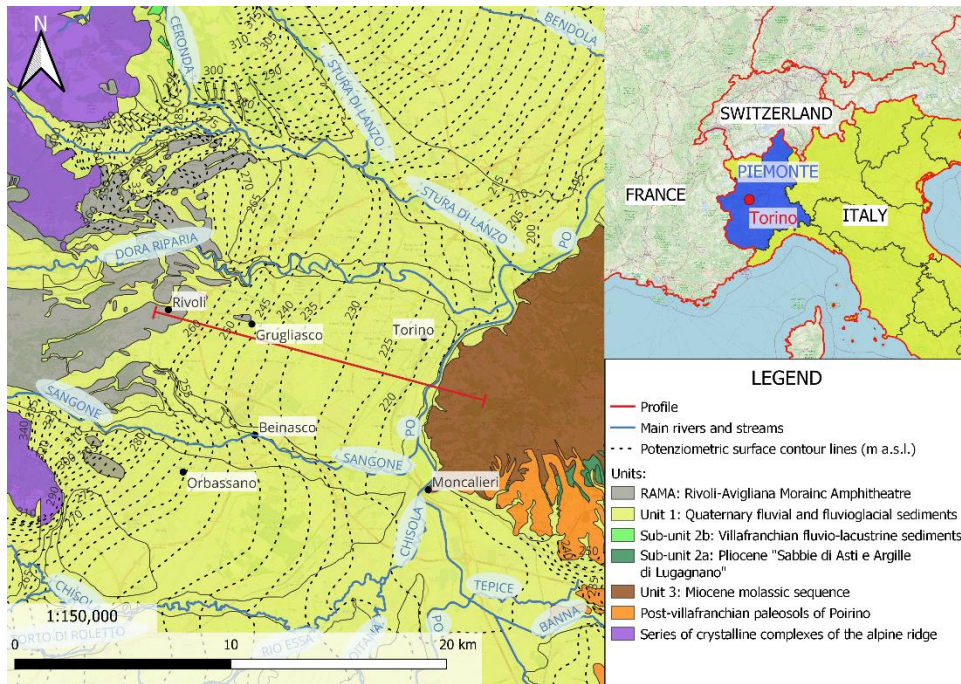
292 The Environmental Risk Assessment (ERA) method, utilized for assessing the environmental status of
293 groundwater bodies as reported above, is a systematic approach employed to scrutinize and evaluate
294 potential environmental risks linked to specific human activities. This methodological framework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

306 **2.3 Case study 1: Città di Torino hydrogeological setting**

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

311 Precisely, the Turin City is located in the Turin plain that extends from the Rivoli-Avigliana Morainic
312 Amphitheatre (RAMA) on its western extreme to Turin Hill on its eastern border (Figure 3). The geological
313 succession is composed by an oldest unit (Unit 3-Miocene), constituted by conglomerates, sandstones
314 and marls typical of the molassic sequence belonging to the Piemonte Tertiary Basin. The upper part is
315 locally characterized by the presence of evaporites belonging to the Messinian Gessoso-solfifera
316 Formation. Unit 3 is stratigraphically overlapped by the subsequent Unit 2 (Pliocene) (surface α) or
317 truncated by the main erosional quaternary surface (γ) and therefore directly in contact with the upper
318 outwash deposits (Unit 1-Quaternary). The youngest unit (Unit 1-Quaternary) is constituted by fluvial and
319 fluvioglacial coarse gravels with subordinate sands and silts (locally cemented) derived from alluvial fans
320 aggraded by the alpine rivers down-streaming towards the east and has an average thickness of about 30-
321 40 m with a general trend decreasing from W to E and N [51].

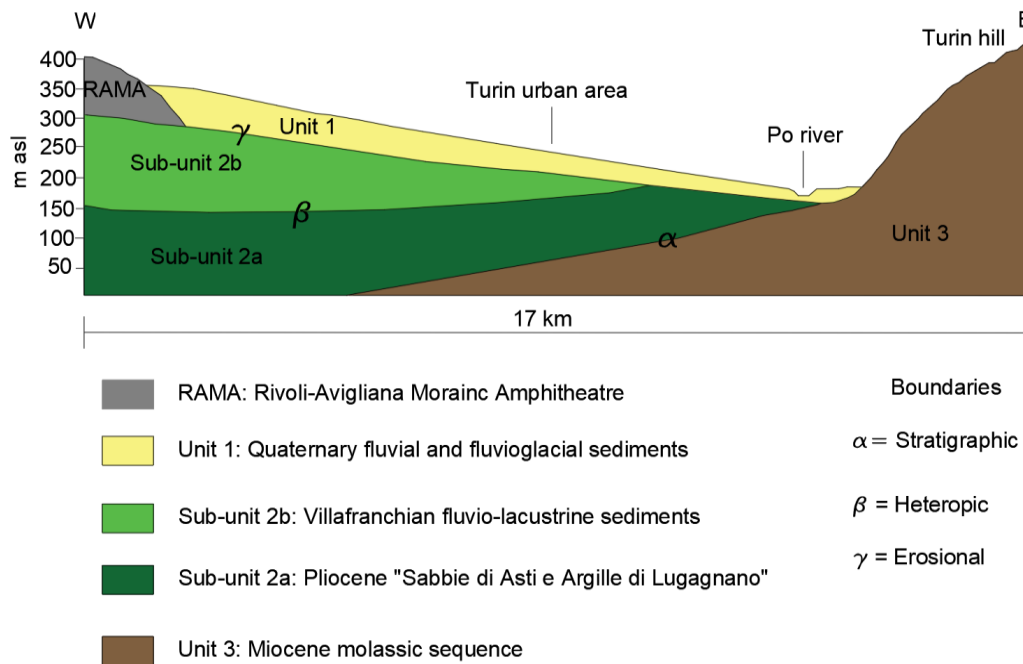
322 The hydrogeological setting is strongly influenced by the presence of the Rivoli-Avigliana Morainic
323 Amphitheatre (RAMA). The buried lithotypes of Unit 3 below Units 1 and 2 (Figure 4) represent the bottom
324 impermeable layer for the unconfined groundwater regional down-flowing towards east mainly
325 developed in the quaternary deposits (Unit 1). Unit 1 represents an important unconfined highly
326 productive aquifer hydraulically connected to the main surface water drainage network (Sangone, Dora
327 Riparia, Stura di Lanzo and Po rivers). The permeability can reach high values (10^{-3} ÷ 10^{-4} ms⁻¹) depending
328 on the local sediment granulometry. The potentiometric surface shows generally a W-to-E gradient,
329 ranging from 0.6-1.2% (mean 0.9%). Unit 2 hosts a highly productive multi-aquifer system intensively
330 pumped for human consumption. Due to the lithological composition and the tectonic setting, Unit 3
331 hosts confined aquifers scarcely productive. In the hilly sector they are exploited mainly for domestic uses
332 [51].



333

334

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



335

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

336

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.

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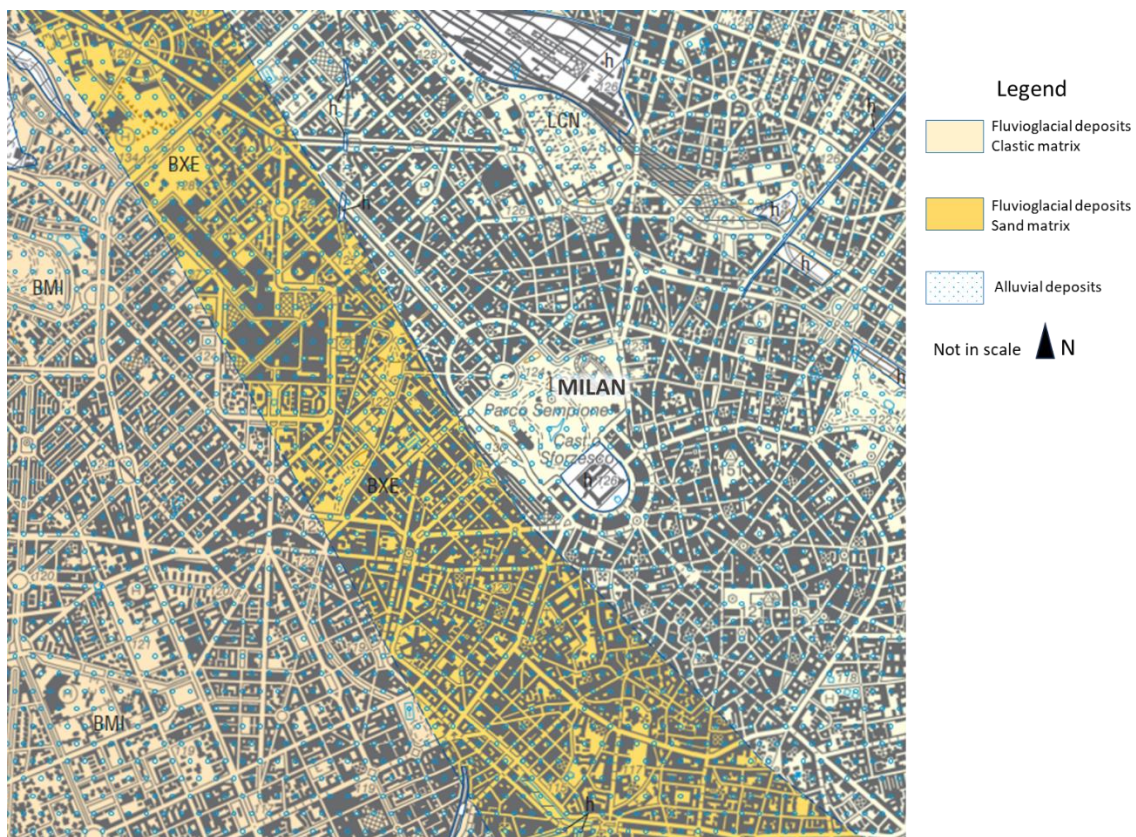
2.4 Case study 2: Città di Milano hydrogeological setting

339

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 southern part. The Po Plain is situated between the Alps and the Apennines thrust belts, evolved as a foreland basin of the Apennines

341

342 from the Messinian [52] while as a distal ramp of the Apennine foreland basin during the Pliocene [53].
343 Milan city lies within the fluvioglacial Riss and fluvial Wurm deposits of the Upper Pleistocene. This area
344 is characterised by the presence of two regional unconformities that have led to the definition of three
345 subsoil units: supersintema Padano (PD), supersintema Lombardo Inferiore (LI) and supersintema
346 Lombardo Superiore (LS). These units sealed the Miocene bedrock, and the upper unit (LS) consists of
347 coarse and medium gravel, clast supported and locally cemented, with subordinate layers of medium and
348 coarse sands and gravelly sands.
349 Fine lithologies, such as silts and clayey silts may be intermittently encountered, and their lateral
350 continuity is often reduced, particularly in association with the upper unit (LS) (Figure 5).

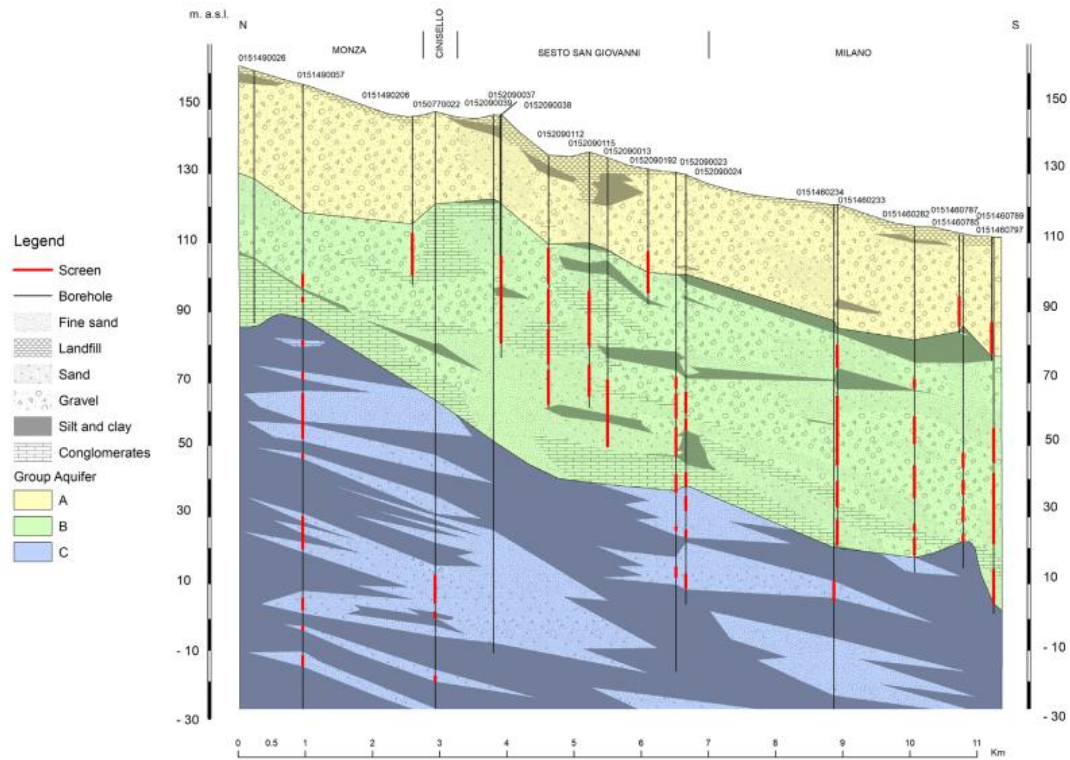


351

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

353 Considering the lithological characteristics, deduced from the wells' stratigraphies in the area, three main
354 hydrostratigraphic units can be recognised, from shallowest to deepest, the Aquifer Group A, B, and C
355 [55,56]: the Aquifer Group A, with an average thickness of 20-50 m from ground level, is composed mainly
356 of highly permeable coarse lithologies (pebbles, gravels, and sands), with subordinate lenticular
357 intercalations of sandy silts and yellow/brown clays. This unit contains the first, most vulnerable aquifer,
358 representing the exploitable resource for geothermal open-loop systems diffusion. The A Aquifer is
359 separated by a clayey silty aquitard (2–5m thick) from the B Aquifer (semi-confined), with an average

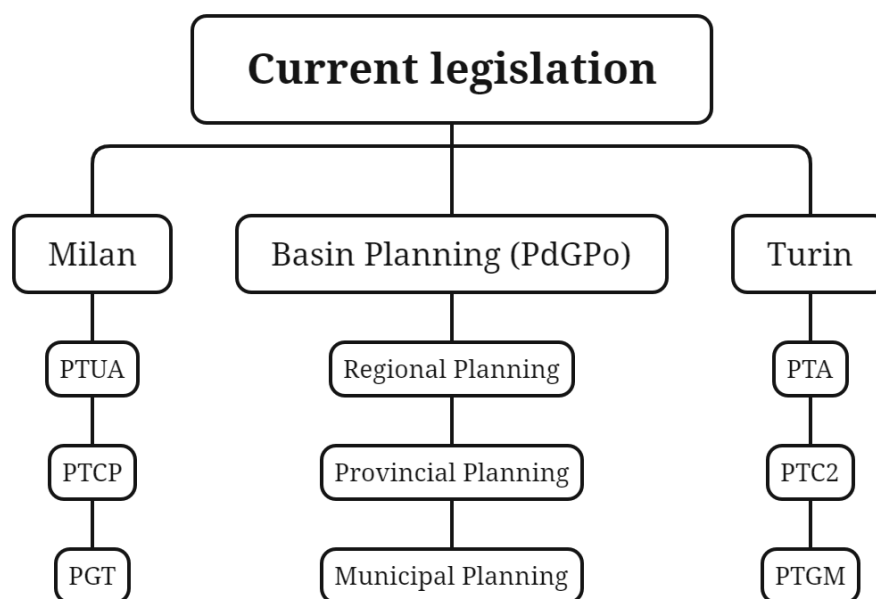
360 thickness of 50-100 m composed of sands and sandy gravels. The deep confined (Aquifer C) consists of
 361 overlapping silty-clayey and fine sand units. In Figure 8 there is a cross-section of a group aquifer
 362 representation [56], that shows the three different aquifers (A, B and C; Figure 6).



363
 364 Figure 6 Hydrogeological cross-section of Milan area [56]

365 **3. Results and Discussion**

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



378

379 Figure 7 Comparison between the described planning instruments for the Piedmont and Lombardy Regions.

380 Acronyms reported are defined in Chapters 2.2.1 (Piedmont Region) and 2.2.2 (Lombardy Region).

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

388 Analogies are evident in the technical documentation required to accompany particular authorization
 389 requests. According to Regional Environmental Energy Plan [57] geothermal heat pumps in the Piedmont
 390 Region have rapidly increased from 2005 to 2015. A further development is expected in the coming years.
 391 As reported in chapter 2.2.1, any new open-loop plant is subject to prior authorisation according to Article
 392 124 of Legislative Decree No. 152/06 and in compliance with the sector regulations on water and subsoil
 393 protection. Authorisations are issued after an investigation aimed at verifying (paragraph 2 - Article 29):
 394 (a) the geometry and hydrochemical characteristics of the water body receptor; (b) the modifications
 395 induced on the morphology of the piezometric surface; (c) changes in the chemistry of the aquifer
 396 concerned by the assessment of effects on the thermal and hydrochemical status; (d) the overlapping
 397 effect of any other geothermal plants insisting on groundwater body in the investigation area. The

398 implementation of at least one control piezometer downstream of the discharge and a preliminary
399 identification of an attention limit for the temperature of the discharged effluent and management
400 discipline in case of exceeding it (between 20-22 °C summer season; 7-8 °C winter season) are mandatory.
401 The reinjection of the thermally disturbed quantity of water into the exploited aquifer, associated with
402 each GWHP is potentially able to cause a significant thermal impact on the aquifer: the technical requests
403 associated with the authorization process, for both Piedmont and Lombardy Regions, have the objective
404 of monitoring and predicting, thus limiting the impact of the alteration produced. Moreover, at the local
405 level, the climate component, together with the recharge conditions and anthropogenic impacts (e.g.,
406 underground infrastructure networks), can have an important influence on the shallow aquifer
407 temperatures. Despite the soil consumption rate in Turin corresponds to 65% [42], the current thermal
408 trend of the shallow aquifer in the Turin area (i.e., about 20 m deep with respect to the surface of the
409 ground floor) shows a relatively stable temperature. As reported in [58], where the authors performed an
410 analysis of the GroundWater Temperature (GWT) over a period of 10 years (from 2010 to 2019), the
411 increasing trend in GWT basically reflects the increase in air temperature. Seasonal variations affect only
412 the superficial part of the aquifer. Anthropogenic impacts on GWT are not significant. This aspect,
413 together with the high productivity of the surface aquifer within Unit 1 (see chapter 2.3), contributes to
414 the creation of favourable conditions for the large-scale use of groundwater heat pumps (GWHP).
415 Therefore, at present, the installation of GWHPs is limited: Fig. 8a shows the wells' diffusion of the Turin
416 city urban area. However, the nature of the data available for the Piedmont Region (i.e., the location of a
417 well associated with an authorization procedure) does not allow professionals to easily identify drilling
418 and extractions built for geothermal purposes. More precisely, considering the available information
419 resulting from consultation of different AUA practices, 44 geothermal plants have been installed in the
420 Turin Province area ([59]; data updated to June 2023) (Figure 8b). No urban census of geothermal wells is
421 available for Turin city: the data proposed in Fig. 8b were gathered by analysing the single environmental
422 authorization (AUA) for extraction wells only, available on the website of the Metropolitan City of Turin
423 [59]. These data were integrated with those available on the ARPA Piedmont website (Figure 8a), thus
424 including injection wells in the map. Conversely, for the city of Milan it is possible to automatically
425 discretize the geothermal plants among all the drilled wells, through the analysis of available data
426 accessing on the [60] (Figures 9a, 9b).

427 In Milan province, more than 209 geothermal plants and associated 796 shallow geothermal wells are
428 present (data updated to June 11, 2021), with a heating capacity of over 4600 KW and a cooling capacity
429 of over 4000 KW [60]. According to what reported in Figure 10, over 86% of geothermal plants are used

430 for residential purposes. In addition, the city area hosts six underground metro lines, and many deep
431 infrastructures' foundations. Anthropogenic and environmental impacts of underground infrastructure
432 networks, land use rates and GWHPs, respectively, have caused variation on the shallow aquifer's
433 temperatures. In their work, [61] described the change in thermal energy stored in the Milan shallow
434 groundwater bodies due to changes in natural and anthropogenic factors such as climate, city size and
435 shallow geothermal installations. Over time, the groundwater thermal regime in Milan urban areas has
436 been governed by the complex superimposition in time and space of positive and negative heat flows
437 from many natural and anthropogenic sources: more than 3°C difference between the surface aquifer

438 temperature was measured in the centre of Milan and the respective rural areas around the city and a
439 warming trend of +0.4 °C/year observed in the city centre.

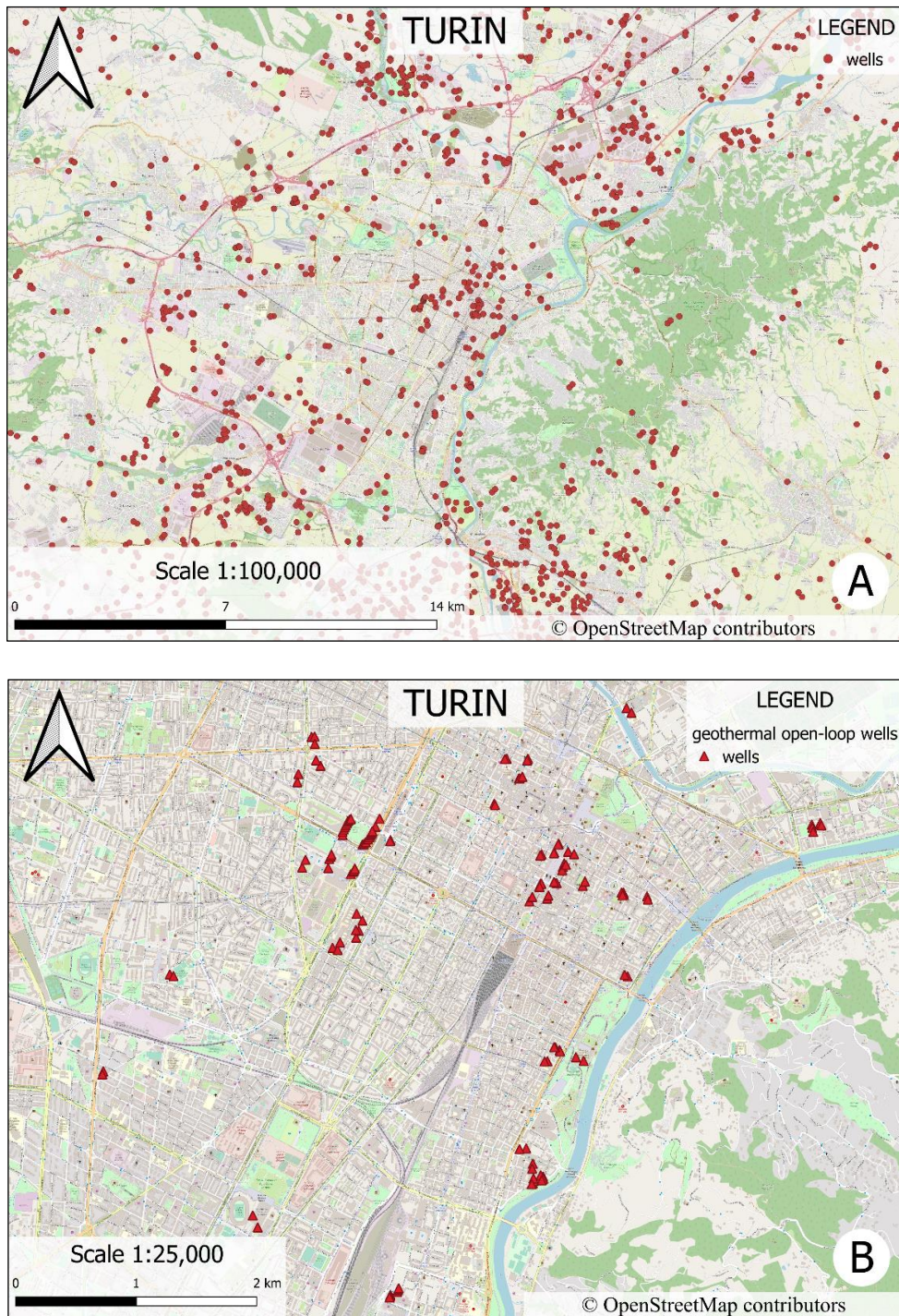


Figure 8 a) Wells in Turin municipality [62]; b) Geothermal open-loop wells in Turin municipality

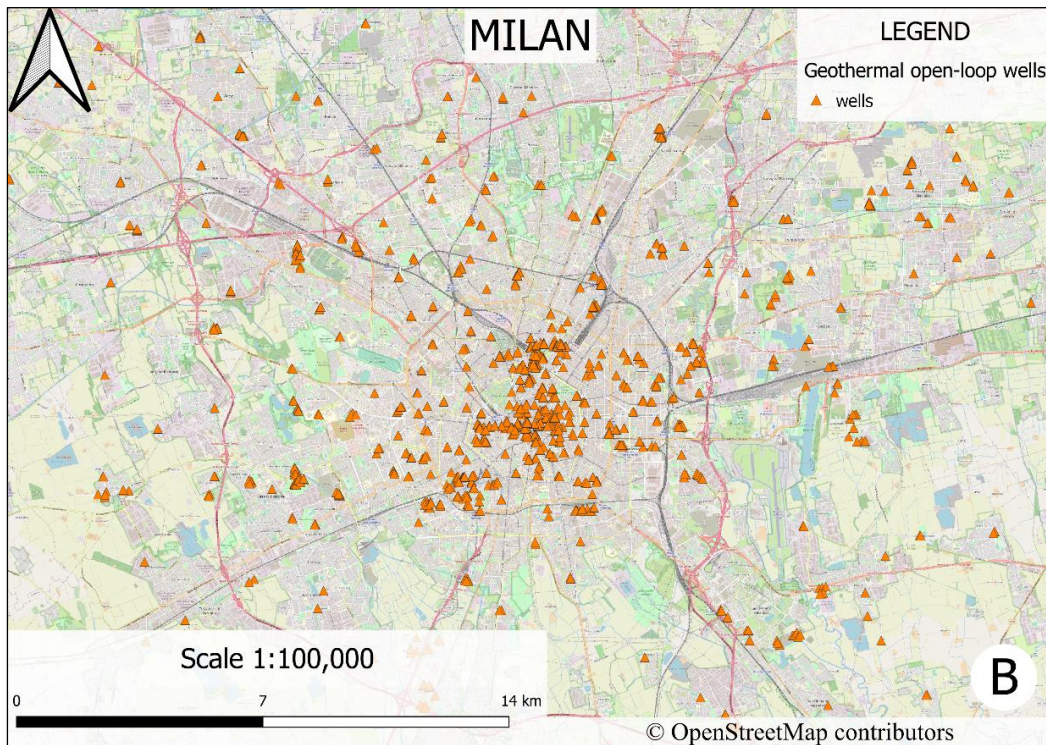
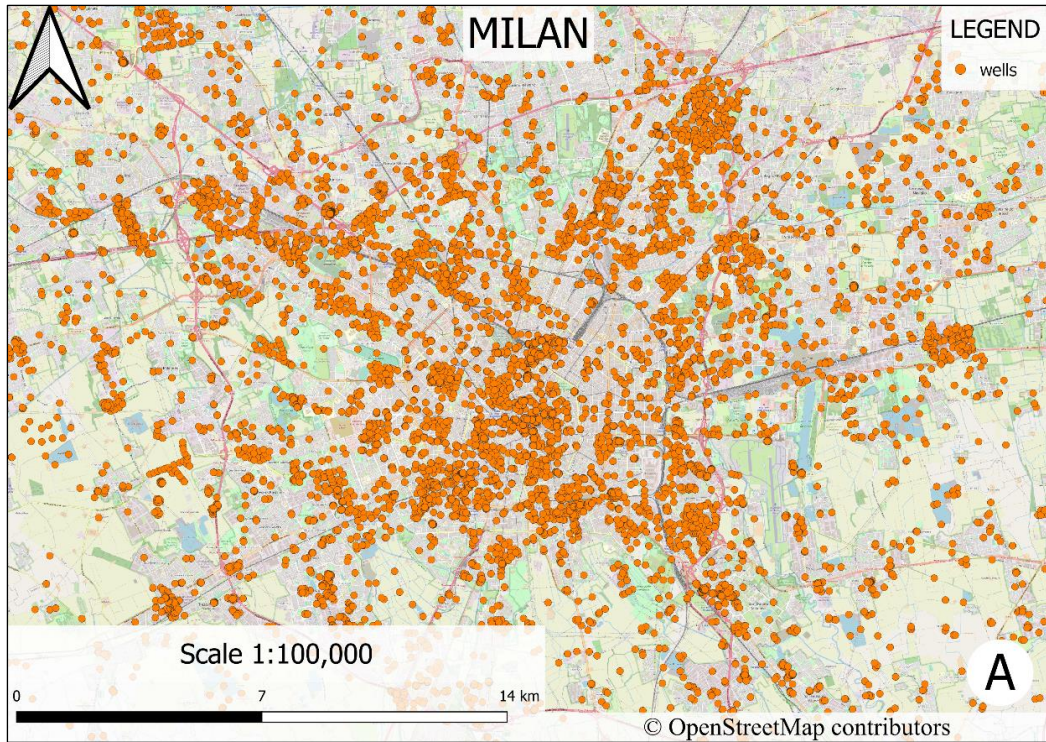


Figure 9 a) Wells in Milan municipality [60]; b) Geothermal open-loop wells in Milan municipality (data from [60])

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

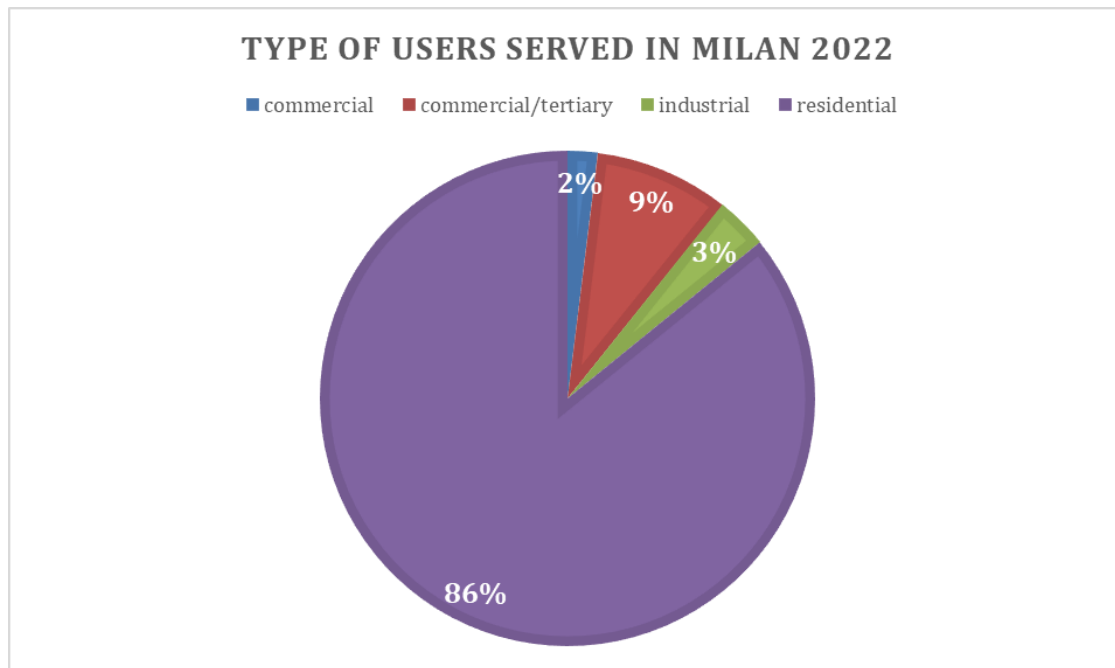


Figure 10 Type of users served in Milan (data from [63])

443 **4. Conclusions**

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

461 understanding of the subsoil in the decision-making process. Working on national-scale regulatory tools
462 and standards is the objective that authorities must pursue.

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

476

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478 contributed to finding materials and using analysis tools. All authors have read and agreed to the
479 published version of the manuscript.

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