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From Gold to Heat: Unlocking Quebec's Mining Legacy through Geothermal Energy

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ABSTRACT

Home to one of the world's most geologically diverse mining sectors, Quebec (Eastern Canada) has a long history of extracting gold, copper, nickel, zinc, and more recently, lithium and rare earth elements. This legacy has left behind over 1,300 closed mines across the province. While many of these sites were once considered environmental and economic burdens, they are now being re-evaluated as untapped sources of clean energy. Over the past decade, INRS has advanced methods to evaluate the geothermal potential of abandoned and flooded mines. This work has redefined how we estimate not only the volume and temperature of mine water, but also the contribution of surrounding rock mass to long-term heat exchange. Abitibi and James Bay areas host the highest concentration of closed mining sites, where communities coexist with active mining operations. In these regions, 17 open-pit mines and 69 underground flooded mines with more than 1,000,000 tons of past production were inventoried and assessed for their geothermal potential for heating and cooling. Results vary significantly by mine size, with annual energy extraction potential peaking at 21,778 MWh for heating and 24,558 MWh for cooling, equivalent to the energy demand of 3,142 and 24,558 homes, respectively. While most sites are well positioned, the largest mines do not always align with high population density, suggesting that viable development depends as much on proximity to end users as it does on total energy potential. Nonetheless, Quebec's unique context, with its cold climate, energy-intensive economy, and a strong desire from municipalities and mining companies to repurpose idle lands, makes it an ideal setting to deploy this technology. This paper outlines the current state of knowledge and tools developed to assess this resource, paving the way for its integration into Quebec's clean energy future.

1 INTRODUCTION

Although mining sites require significant investment to operate, they have always been considered to have little value after closure. The reasons for their abandonment have most often revolved around the depletion of their mineral resources, non-compliance with mine safety requirements or political decisions (Asr et al., 2019), as well as the absence of a mine reclamation and post-mining management plan by legislative authorities (Laurence, 2006). However, the situation can sometimes change, and there is now a growing interest in their reuse. There are indeed positive uses for mines that are now inactive, in particular with the production of renewable geothermal energy (Peralta Ramos et al., 2015; Loredo et al., 2016; Al-Habaibeha et al., 2018). While most inactive mining areas are economically and residentially deserted, those with nearby heating or cooling demands hold the greatest potential for development.

Once closed, underground tunnel networks and open pits are flooded with ground and runoff water. This volume of water, maintained at a constant temperature throughout the year by the terrestrial heat flow, has a thermal content that can be exploited with geothermal heat pumps to meet the heating and cooling needs of businesses and residential areas. As this groundwater occupies cavities (open pits or underground workings) that were dug during mining operations, it is accessible without the need for drilling, which is often the main expense associated with geothermal energy recovery. This technology would benefit to the population where municipalities wish to give a second life to dormant mine sites (Grasby et al., 2012; Raymond and Therrien, 2014).

Existing approaches for geothermal resource assessment at mine sites often rely solely on static energy contained in the mine water, resulting in underestimation of available thermal energy (Chicco et al., 2021). Recognizing the limitations of static energy content estimation, recent studies advocate for comprehensive heat

balance models that incorporate dynamic energy contributions from host rock into the assessment of abandoned and flooded underground mines (Ngoyo Mandemvo et al., 2023; Lacombe et al., 2025).

However, many questions remain unanswered before the exploitation of this renewable energy can have a lasting impact on communities. With the emergence of this new exploitation channel for post-mining companies, a technically sound and economically viable business case needs to be defined in order to attract industrial and municipal partners with energy needs adapted to local geothermal resources. That's why it's vital to deploy tools to easily assess the amount of energy a closed mining site can supply. Thus, the objective of this paper is to establish a comprehensive inventory of closed mining sites geothermal potential within the Abitibi and James Bay regions (Quebec, Eastern Canada), considering recent improvements in resource assessment method and the proximity to local communities. We identify the most promising sites and estimate their thermal geothermal potential for heating and cooling, providing at the same time a foundational framework for the technical characterization criteria that could be use elsewhere.

2 METHODOLOGY

We focused on the Abitibi and James Bay regions to apply our improved geothermal resource assessment method because they contain the highest concentration of closed mining sites in Quebec and still support substantial populations due to ongoing mining activity. Using Arkay's inventory (1980), all abandoned mines with over 1,000,000 tons of past production were selected, totalling 17 open pit and 69 underground flooded mines. Only two parameters were available to support a preliminary geothermal assessment: (1) total ore production (tons) and (2) the maximum depth reached during mining operations. We then assumed a geothermal gradient of 10 °C/km (Mareschal et al., 1989) and a mean surface temperature of 2 °C (Environment Canada, 2025). Based on these inputs, we derived first-order estimates of mine-water volume and temperature, which were integrated into a thermal balance calculation to quantify the available geothermal resource for heating and cooling.

2.1 Mine water volume

Mine-water volume (V) was estimated from total ore extracted, assuming a universal host-rock density. For underground mines, we assumed that a significant portion of the workings is occupied by backfill, reducing the volume available for water.

$$V = \frac{O}{\rho} \times \frac{100-B}{100} \tag{1}$$

The water volume V is defined in m^3, the ore production O in kg, where 1 ton equals 1,000 kg, the rock density ρ is assumed 2,700 kg m^{-3}, and the fraction of underground workings containing backfill B is assumed 75%.

2.2 Achievable mine water temperature change

Two different equations are required, depending on whether the use is heating or cooling, to determine the maximum temperature variation. The minimum extraction temperature can be down to 2 °C for heating and the maximum extraction temperature up to 25 °C for cooling. The resulting temperature differential is calculated by estimating the average water temperature based on the surface temperature, the geothermal gradient, and the maximum mine depth (Figure 1).

$$\Delta T_{\text{heating}} = T_{\text{surface}} + \frac{D \times G}{2 \times 1000} - 2 \tag{2}$$

$$\Delta T_{\text{cooling}} = 25 + \frac{D \times G}{2 \times 1000} - T_{\text{surface}} \tag{3}$$

The parameters consist of the maximum mine depth D in m, the geothermal gradient G at 10 °C/km, and the mean surface temperature $T_{surface}$ at 3 °C.

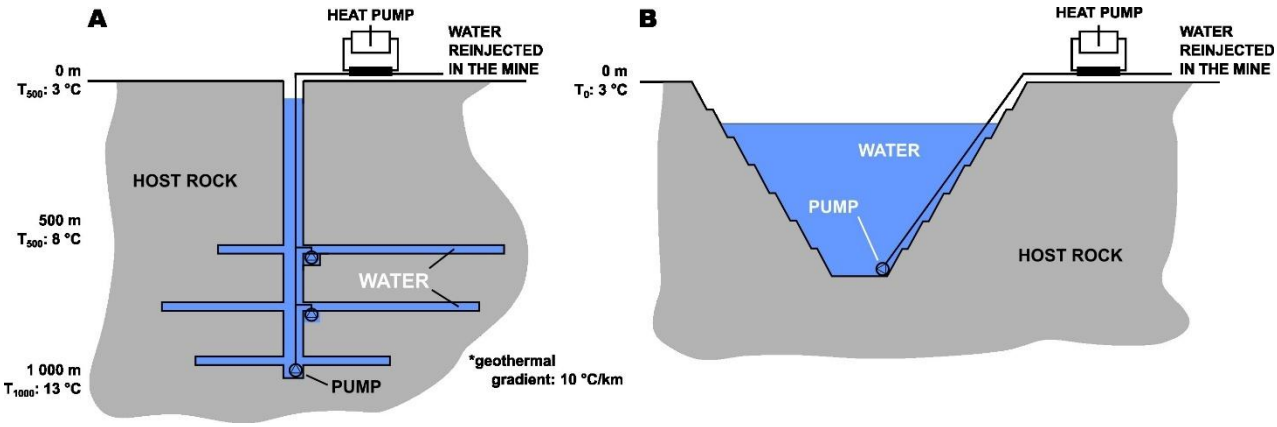


Figure 1. Conceptual temperature–depth conceptual model assuming a geothermal gradient of 10 °C/km for: A) an underground mine, and B) an open-pit mine.

2.3 Heat balance calculation

The thermal energy extractable from a mine depends on several key parameters. These include the volume of water in the mine, the achievable temperature change for heating or cooling, and the specific heat capacity of water. The system lifetime is also considered to calculate a power output, typically 25 years (25 y × 365 d/y × 24 h/d × 3,600 s/h). Finally, the extractable mine-water energy is multiplied by a correction factor (R) to account for the thermal contribution of the surrounding host rock. This factor represents the energy released as water temperatures fluctuate over a 25-year operational lifespan. The values of 5 for underground mines and 1.2 for open-pit mines are based on studies in the Northwest Territories (Ngoyo Mandemvo et al., 2023) and in Quebec (Lacombe et al., 2025), both situated in a Canadian context.

$$P_{\mathrm{n}} = \frac{V \times \Delta T \times c}{t_{\mathrm{n}}} \times R \tag{4}$$

The variables include the mine thermal energy P_{n} in MW, the achievable temperature change for heating or cooling ΔT in °C, the water heat capacity c estimated at 4.184 MJ m^{-3} K^{-1}, the system lifetime t_{n} in seconds (where 25 years is calculated as 25 yx 365 d/yx 24 h/dx 3,600 s/h), and the correction factor for host rock R, which is 5 for underground mines and 1.2 for open-pit mines.

2.4 Geothermal energy production made available for space heating and cooling

The final geothermal energy produced for heating or cooling buildings is different from what is extracted from the mine system and can be estimated considering the heat pump coefficient of performance with two separate equations for heating and cooling modes. These calculations rely on the mine's thermal power influenced by the water and host rock, the electric power required for the heat pump, and the heat pump's coefficient of performance. From these parameters, the total available power and the annual geothermal energy yield can be determined.

The total available power P_{tot} in MW and the total annual available geothermal energy E_{tot} in MWh are determined by the mine thermal energy P_{n} in MW, the electric power required for the heat pump P_{hp} in MW, and the coefficient of performance of the heat pump in heating mode COP_{heating} and cooling mode COP_{cooling}, which are typically 3.5 and 4.5.

2.4.1 Heating

$$P_{hp} = \frac{P_n}{COP - 1} \tag{5}$$

$$P_{tot} = P_n + P_{hp} \tag{6}$$

2.4.2 Cooling

$$P_{hp} = \frac{P_n}{COP + 1} \tag{7}$$

$$P_{tot} = P_n - P_{hp} \quad (8)$$

2.4.3 Total annual geothermal energy available for heating or cooling

$$E_{tot} = P_{tot} \times 24\frac{h}{d} \times 365\frac{d}{y} \quad (9)$$

2.4.4 Number of houses that can be heated and cooled

To illustrate the scale of the energy involved, we converted the results into the number of homes that could be heated or cooled annually, based on average energy consumption provided by Hydro-Québec for the Abitibi and James Bay regions. These values correspond to 20,000 kWh/year per home for heating and 1,000 kWh/year per home for cooling.

3 RESULTS

A total of 86 flooded mines, comprising 69 underground and 17 open-pit operations, with historical production exceeding 1,000,000 tonnes were analyzed. Geothermal potential was calculated based on a heat pump exploitation model and converted into the equivalent number of households served (Tables 1 and 2).

The study revealed a significant variation in energy capacity across both mine types. For underground mines (Table 1), annual heating potential averaged 960 MWh (could serve 48 homes), with peaks at the Horne and Lamaque mines reaching 21,778 MWh (1,089 homes). Cooling potential for these sites averaged 1,764 MWh, led by Horne and East Malartic. Conversely, open-pit mines showed a average heating potential of 829 MWh, while their cooling potential was substantially higher, averaging 5,550 MWh. The highest cooling capacities were identified at Lac Troilus and Lac Matagami, which could theoretically serve 24,558 and 19,225 households, respectively.

The regional distribution of these resources across the Abitibi and James Bay regions, illustrated in Figure 2, highlights the critical intersection of energy potential and urban proximity. Residential occupant density was assessed at a 50-meter resolution using 2021 data from Quebec's *Ministère des Affaires municipales et de l'Habitation*, incorporating property assessment rolls and 2021 census data at the dissemination area scale. This high-resolution mapping allows for a nuanced assessment of feasibility based on the proximity of end users.

The analysis identifies Rouyn-Noranda, Val-d'Or, Chibougamau, and Matagami as the four municipalities with the highest concentration of mining sites located near populated areas (Figure 2). Strategic findings emphasize that raw energy potential does not always guarantee project viability; for example, high-capacity sites like Selbaie and Lac Troilus are isolated, located more than 100 km from the nearest major town, which limits their practical appeal due to infrastructure costs. In contrast, the municipalities of Rouyn-Noranda and Val-d'Or host a multitude of mines of varying sizes within their municipal limits, offering immediate opportunities to convert dormant geothermal energy sources from mine sites. Similarly, Matagami and Chibougamau contain several modest-sized sites that represent strong candidates for localized geothermal development.

Table 1. Closed underground mines in Abitibi and James Bay and their geothermal potential.

UNDERGROUND MINES	Max Depth (m)	Production (tons)	Annual Heating Energy MWh_{total}	Heated houses (20,000 kWh/y)	Annual Cooling Energy MWh_{total}	Cooled houses (1,000 kWh/y)
Horne	2,440	59,300,000	21,778	1,089	11,267	11,267
Lamaque	1,722	22,519,000	5,837	292	5,701	5,701
East Malartic	550	17,948,457	1,486	74	6,394	6,394
Louvicourt	965	15,900,000	2,309	115	5,084	5,084
Quémont	1,259	15,400,000	2,918	146	4,526	4,526
East Sullivan	1,219	15,186,638	2,786	139	4,517	4,517
Copper Rand	1,374	14,066,990	2,909	145	3,992	3,992
Springer	655	12,500,000	1,232	62	4,338	4,338
Kiena	930	10,565,872	1,479	74	3,411	3,411
Bouchard-Hébert	320	10,187,531	491	25	3,835	3,835
Normétal	987	10,084,300	1,498	75	3,205	3,205
Beattie	620	9,645,000	900	45	3,377	3,377
Perry	452	9,000,000	612	31	3,284	3,284
Malartic Gold Fields	860	8,958,700	1,160	58	2,947	2,947
Camflo	1,200	8,862,240	1,601	80	2,650	2,650
Barnat	707	8,454,034	900	45	2,895	2,895
Henderson II	757	8,315,883	948	47	2,811	2,811
Bousquet No 2	1,380	7,375,258	1,532	77	2,089	2,089
Telbel	1,219	6,168,773	1,132	57	1,835	1,835
Barvue	166	5,722,136	143	7	2,232	2,232
Portage	1,097	5,636,337	931	47	1,737	1,737
Poirier	869	4,847,749	634	32	1,591	1,591
Sullivan	972	4,613,500	675	34	1,472	1,472
Norbec	440	4,350,000	288	14	1,592	1,592
Joe Mann	1,145	4,289,221	739	37	1,304	1,304
Norita	512	3,940,382	304	15	1,417	1,417
Millenbach	1,213	3,900,000	712	36	1,162	1,162
Cedar Bay	1,036	3,860,707	602	30	1,210	1,210
Molybdenite Corporation	175	3,828,844	101	5	1,490	1,490
Casa Berardi	870	3,700,000	485	24	1,214	1,214
Bell Allard	1,025	3,589,000	554	28	1,129	1,129
Bevcon	686	3,268,243	337	17	1,125	1,125
Géant Dormant	295	3,158,698	140	7	1,196	1,196
Corbet	800	3,060,000	368	18	1,023	1,023
Isle-Dieu	610	3,050,108	280	14	1,071	1,071
Siscoe	774	2,975,765	347	17	1,001	1,001
Silidor	614	2,959,091	273	14	1,038	1,038
Stadacona	1,253	2,742,000	517	26	807	807
Powell-Rouyn	978	2,715,000	400	20	865	865
Lac Shortt	500	2,700,000	203	10	974	974
Francoeur	377	2,607,563	148	7	969	969
Louvem	460	2,358,200	163	8	859	859
Preissac Molybdenite	410	2,235,880	138	7	824	824
Belleterre	778	2,177,400	255	13	732	732
Marban	259	1,983,112	77	4	757	757
Cooke	609	1,973,188	181	9	693	693
Aldermac	495	1,893,215	141	7	684	684
Wasamac	384	1,892,448	109	5	702	702
Henderson I	305	1,831,621	84	4	692	692
New Hosco	323	1,826,635	89	4	687	687
Lucien C. Béliveau	300	1,800,298	81	4	681	681
Ferderber	500	1,710,102	129	6	617	617

UNDERGROUND MINES	Max Depth (m)	Production (tons)	Annual Heating Energy MWh_{total}	Heated houses (20,000 kWh/y)	Annual Cooling Energy MWh_{total}	Cooled houses (1,000 kWh/y)
Senator Rouyn	845	1,632,960	208	10	539	539
Icon	335	1,616,567	82	4	606	606
Perron	686	1,611,368	166	8	555	555
Ansil	1,200	1,600,000	289	14	479	479
Norlartic	305	1,544,453	71	4	583	583
Gallen	780	1,537,671	181	9	517	517
Joutel Copper	328	1,450,000	72	4	545	545
Chadbourne	411	1,427,000	88	4	526	526
East Waite	634	1,361,000	130	6	475	475
Copper Cliff	533	1,273,819	102	5	456	456
Mouska	950	1,217,047	174	9	391	391
Mine O'Brien	550	1,148,750	95	5	409	409
Peel-Elder	793	1,110,371	133	7	372	372
Bras D'Or	320	1,106,812	53	3	417	417
Yvan Vézina	183	1,095,191	30	2	426	426
Jaculet	537	1,090,600	88	4	390	390
Norita-Est	900	1,080,000	146	7	352	352

Table 2. Closed open-pit mines in Abitibi and James Bay and their geothermal potential.

OPEN-PIT MINES	Max Depth (m)	Production (tons)	Annual Heating Energy MWh_{total}	Heated houses (20,000 kWh/y)	Annual Cooling Energy MWh_{total}	Cooled houses (1,000 kWh/y)
Lac Troilus	320	67,946,868	3,142	157	24,558	24,558
Selbaie	310	53,067,381	2,377	119	19,225	19,225
Lac Matagami	228	25,572,269	842	42	9,441	9,441
Sigma	914	25,214,706	3,330	167	7,848	7,848
Doyon	130	24,563,617	461	23	9,272	9,272
Manitou-Barvue	999	13,750,120	1,985	99	4,181	4,181
Bousquet No 1	40	10,923,753	63	3	4,206	4,206
Waite	390	8,760,496	494	25	3,114	3,114
Waite-Amulet	229	6,480,000	214	11	2,392	2,392
Don Rouyn	33	5,179,000	25	1	1,997	1,997
Persévérance	300	5,120,000	222	11	1,859	1,859
Principale	244	4,792,900	169	8	1,763	1,763
Orchan	505	4,514,367	329	16	1,561	1,561
Merrill Island	533	2,506,000	193	10	861	861
Joliet	366	2,080,000	110	6	744	744
Sigma-2	300	1,880,000	81	4	683	683
Cadillac Moly	213	1,761,200	54	3	652	652

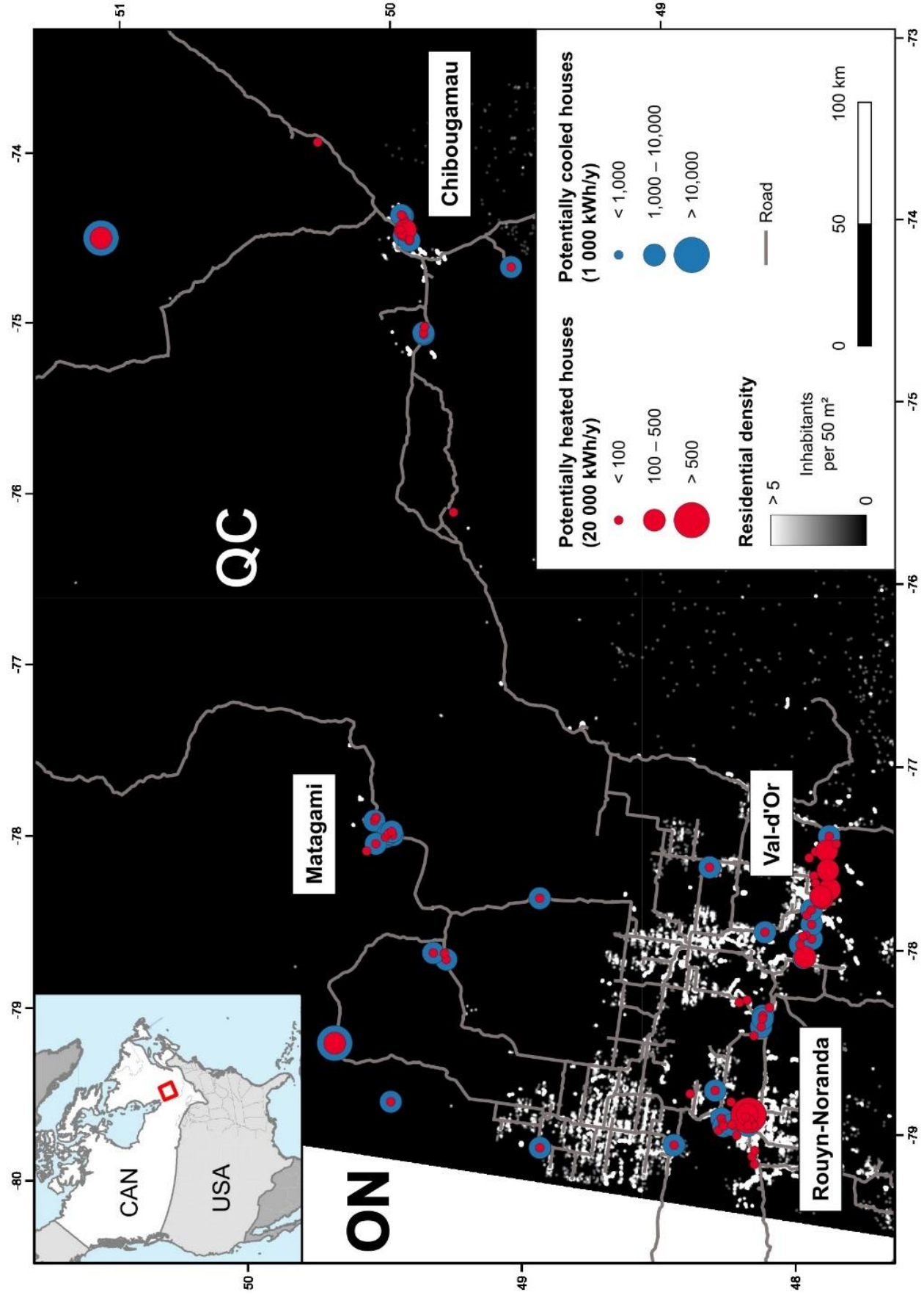


Figure 2. Geothermal potential of closed mines in Abitibi and James Bay for home heating and cooling. Residential occupancy density data provided by Quebec's *Ministère des affaires municipales et de l'habitation* (2021). Abbreviations: ON, Ontario; QC, Quebec.

4 DISCUSSION AND PERSPECTIVES

Several assumptions were made to overcome the geometry factor in the calculation of the geothermal energy potential of abandoned mines. The most noteworthy are the percentage of backfilling of the mine workings after the closure as well as the correction factor for the heat exchange rate from the rock upon heating or cooling the water, which is taken into account in the heat balance calculation. The backfilling was assumed to be 75% for all underground mines, but it is considered to be a conservative estimation because it is quite possible that this ratio is lower or even non-existent for old mines, which can increase the volume of water in place proportionally. In this case, the geothermal potential, whether for heating or cooling, would proportionally increase. To account for the heat exchange contribution of the host rock, the thermal contribution for an underground mine was set five times more than the mine water. This ratio was based on numerical simulations of the Con Mine in the Northwest Territories, Canada (Ngoyo Mandemvo et al., 2023). This depends greatly on the geometry of the underground workings, their diameter, and whether they are more or less distributed at depth, etc. For open-pit mines, the host rock's heat exchange contribution factor was 1.2. This modest value was validated through numerical simulations of a case study in the Thetford Mines region of southern Quebec (Lacombe et al., 2025). The contribution factor for open-pit mines was shown to be substantially smaller than that for underground mines because the rock surface to miner water volume ratio is smaller.

This preliminary study highlights the geothermal and economic potential of flooded, closed mines in Abitibi and James Bay. The size and urban proximity of these sites suggest they could potentially supply energy to residential buildings and small industries (Figure 2). However, the findings reveal a proximity-potential paradox, where we believe that the economic viability of these geothermal resources is more importantly governed by their distance to end users than by their total energy capacity. While sites like Selbaie and Lac Troilus form massive thermal reservoirs, they remain stranded assets due to the prohibitive infrastructure costs required to transport heat over 100 km from Matagami or Chibougamau, which are the closest towns. These isolated mine sites likely require the co-location of high-demand industrial users, such as greenhouses or data centres, to become feasible.

In contrast, the urban-mining legacy in Rouyn-Noranda and Val-d'Or offers immediate opportunities for energy transition. The concentration of mining infrastructure within municipal limits allows for the integration of geothermal energy into high-density residential and commercial sectors with minimal logistical barriers. In these areas, even modest-sized mines can be networked into decentralized clusters to provide a stable, carbon-neutral thermal supply for municipal infrastructure.

While conversion of existing infrastructure from conventional electricity heating/cooling to geothermal heating/cooling may be cost-prohibitive, current demands for affordable housing and local agriculture could drive new construction. It is important to note that potential revenues generated by such projects are on a much smaller scale than those generated with mining activities. Using mine water for geothermal heating and cooling will not generate a « gold rush » nor a means to intensify mining under the guise of circular economy strategies. Closed mines remain a social and environmental challenge. Nevertheless, their potential reconversion offers opportunities to explore alternative regional development models for Quebec and Canada.

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