Mapping the Potential of District Heating Networks in Metropolitan France

Algorithmic and Mathematical Optimization

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1 Abstract

District heating networks are widely recognized as a key lever for France's energy transition and energy sovereignty. They also carry political and social implications, as their implementation falls under the responsibility of municipalities, which must therefore organize themselves to develop such systems. In this context, this research article precisely assesses which French municipalities are eligible for a district heating network and, where applicable, identifies which buildings should be included in order to maximize transported energy under a profitability constraint.

This study develops an algorithmic procedure to process all municipalities in France, relying on building energy consumption data estimated by Cerema (national environmental research institute) and the French road network data from BDTOPO. Profitability constraints are based on the network's linear heat density, which must be at least 1.5 MWh per meter per year—a profitability threshold defined by ADEME—as well as on minimum building energy consumption and a minimum number of buildings required for a viable network.

We therefore developed an algorithm that, using real-world data, can map a potential district heating network for a single municipality, then for all municipalities within a department, and ultimately generalize the analysis to all departments in order to derive national-level results. This national assessment is based on comparisons with existing demand estimation methods developed by Cerema and with data on already operational

networks provided by the EnRezo platform and Fedene. We identify a total of $8,285$ potential networks across the $34,745$ municipalities of metropolitan France, compared with approximately $1,000$ networks currently in operation.

The strength of our model lies in its high level of precision—since the network layout follows the actual road network—its computational efficiency (an average processing time of 20 minutes per department), and its easy replicability through modification of assumptions using publicly available databases.

2 Introduction

District heating networks are systems that deliver heat simultaneously to multiple buildings through a network of pipes. Heat pumps can also be integrated to raise the temperature of the water in order to better meet the building's direct heating needs. District heating networks have a major role to play in the energy transition, particularly within national and European mitigation strategies, which aim to scale up the development of renewable thermal energy. Indeed, they enable the mobilization of local renewable energy sources that would otherwise remain untapped (such as deep geothermal energy or waste heat), resulting in very low CO emission levels (50 to 100 gCO.kWh^{-1} for a biomass-based network, compared with more than 200 gCO.kWh^{-1} for fossil fuel-based supply). They are also a powerful tool for territorial energy planning due to their adaptability to a wide range of energy and geographical contexts [1].

In this context, ADEME, through the national France Chaleur fund, provides financial support—subject to eligibility criteria—to district heating networks primarily supplied by renewable and recovered energy sources. A minimum linear heat density of 1.5MWh.ml^{-1}.year^{-1} (where ml denotes linear meters of network) is required [2], along with a minimum annual peak power demand of at least 30 kW per building. Indeed, above this threshold, it becomes mandatory to carry out a feasibility study assessing the potential connection to a district heating network for new buildings or buildings placed on the rental market [3].

Against this backdrop, our study sought to identify the municipalities where it would be most relevant to build or further develop a district heating network, based on the criteria described above. A key objective was to obtain results as close as possible to real-world conditions. For this reason, we used GIS data from the BD TOPO database [4] to obtain the exact layout of roads beneath which the pipes would be installed, along with building-related consumption data provided by Cerema [5]. The largely untapped potential of municipalities and the methods for identifying it are discussed in the article by Rémi Patureau, Cong Toan Tran, Valentin Gavan, and Pascal Stabat, *The New Generation of District Heating and Cooling Networks and their Potential Development in France* [6]. However, our study adopts a much more precise approach, as it is based on building-by-building assessments and follows actual road layouts rather than straight-line approximations across zones. In this respect, although our method is very similar to the Cerema approach through its EnRezo platform and is based on the same building databases, it provides significantly greater precision in terms of network routing and evaluation [8] and [9].

Our methodology builds upon that developed by Charlotte Gressel in *Assessing High-Potential Areas for the Development of District Heating Networks in France* [10]. The present study extends this work by refining certain assumptions, optimizing or transforming the algorithms, and using a different buildings database. The previous approach relied on ground surface area and building energy performance certificate (EPC/DPE) ratings, which resulted in the exclusion of many buildings lacking such data. All codes, methodology, results, and part of the databases are available on GitHub [11].

The following section presents the implemented methodology and describes the key algorithms. We then present the results at the municipal, departmental, and national scales, including comparisons with Cerema's methodology and findings [8] and [12], the EnRezo mapping platform for district heating networks [9], and real-world data from the Fedene report [13]. Finally, we discuss limitations and future research directions.

3 Methodology

3.1 General Approach

A municipality-by-municipality approach was adopted. The objective is to determine whether a municipality is eligible for the establishment of a district heating network and, where applicable, to design the most optimal network in terms of transported energy. The method relies on real geographical data for roads and buildings, as well as heating and domestic hot water consumption data estimated by Cerema.

3.2 Pathfinding Algorithms

Buildings are transformed into NodeBuilding objects carrying two pairs of coordinates: the building's location and its orthogonal projection onto the road network. They are sorted in descending order of energy consumption.

Roads are also segmented at intersection points—both road–road intersections and road–building projection intersections. The set of neighboring nodes for each intersection point is then computed. Two successive Dijkstra algorithms are applied to the building list. The first computes a dictionary containing the distance from each building to the initial "power plant." By default, this starting point is the highest-consuming building, which is assumed to be connected to the network from the outset; however, this assumption is discussed later.

The algorithm then proceeds as follows: (Figure 2)

A building is selected in descending order of heat demand. Using Dijkstra's algorithm, its distance to the existing network is computed—that is, the distance to the closest point already connected to the network—through a neighbor-by-neighbor approach. We then evaluate whether the ratio of total transported energy to total network length satisfies ADEME's profitability threshold [2]. If the condition is met, the building and the corresponding connecting nodes are added to the network. Otherwise, the building is skipped. The remaining buildings are re-evaluated if at least one building has been added during the previous iteration.

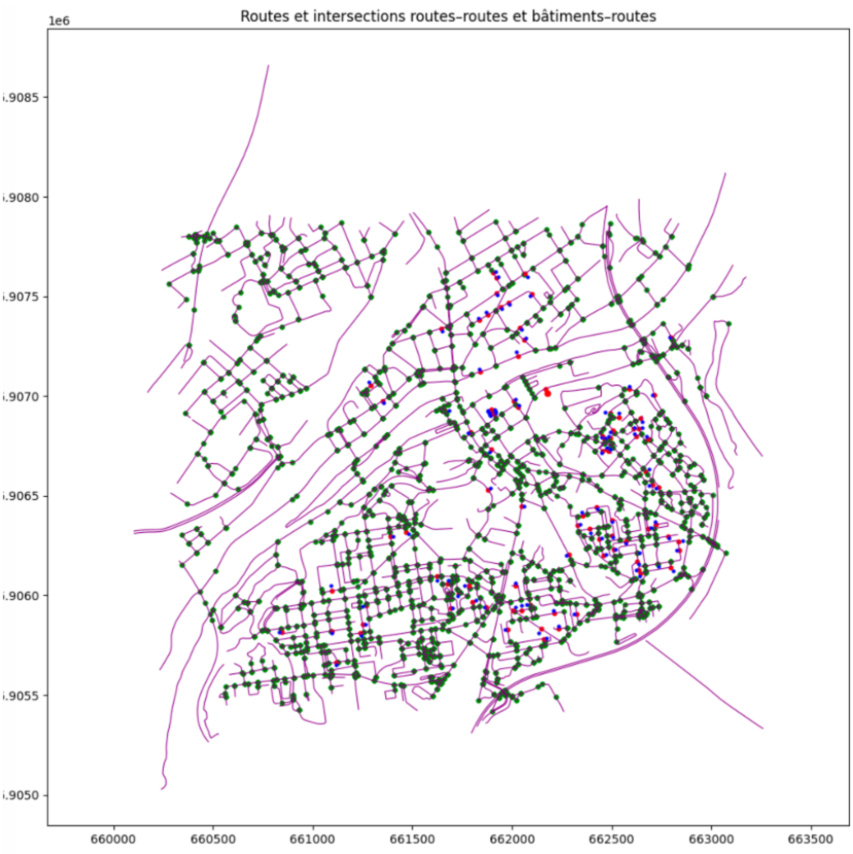

Figure 1: Intersections

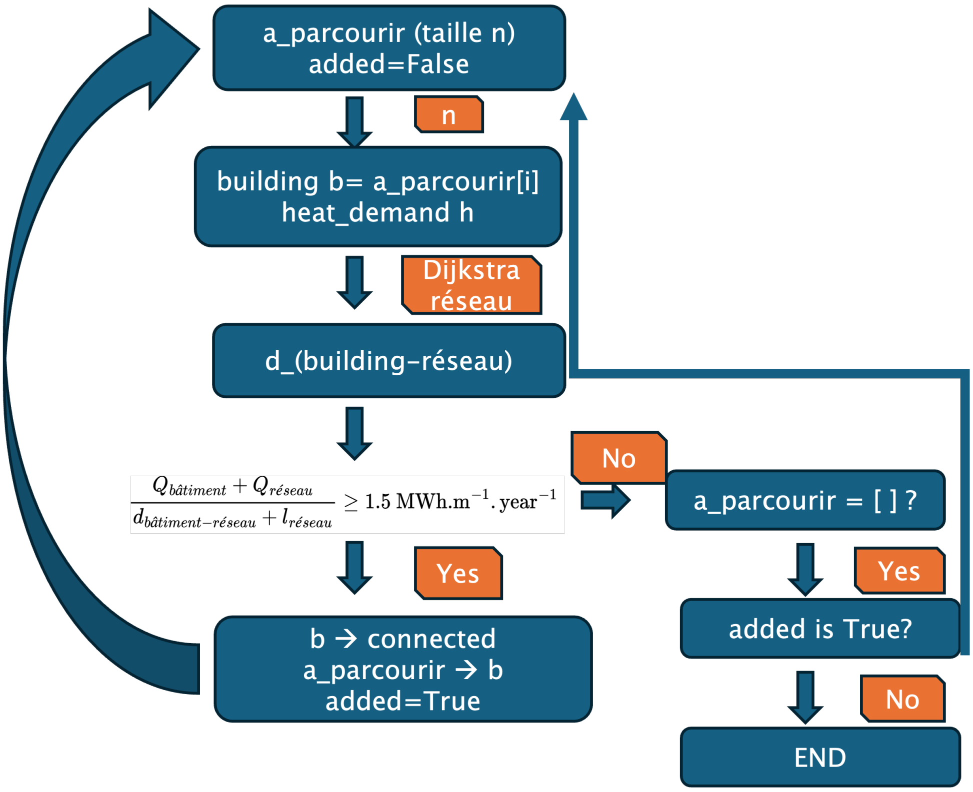

Figure 2: Simplified Algorithm

3.3 Assumptions

3.3.1 Database Used

Initial modeling attempts relied on geographical data from the French National Building Database (BDNB) for both roads and buildings [4]. However, due to the lack of precise energy data, only buildings with available EPC (DPE) information could be used. This allowed for a rough estimation of energy demand but resulted in the loss of approximately 90% of buildings.

The decision was therefore made to rely on Cerema databases [5] and [7], which estimate the energy consumption of each building based on floor area, building type (residential, tertiary, sports facilities, etc.), and unit consumption ratios r provided by CEREN (2023) for heating and domestic hot water. These ratios depend on construction year, dwelling type (for residential buildings), and activity sector (for tertiary buildings).

A climate correction factor is applied to heating demand using unified degree days (base 18°C, averaged over 10 years):

$$CorrClimat_{dept} = \frac{DJU_{moy,dept}}{DJU_{moy,France}} \tag{1}$$

An altitude correction factor is also introduced:

$$CorrAlt_{IRIS} = 1 - 0.65 \times \frac{alt_{IRIS} - alt_{dept}}{DJU_{dept}} \tag{2}$$

Then we have :

$$\boxed{HeatDemand = r \times S_{to-heat} \times CorrClimat_{dept} \times CorrAlt_{IRIS}} \tag{3}$$

with r the unit consumption ratios and $S_{to-heat}$ the surface of the building to heat.

We also have :

$$\boxed{DomHotWater = r \times S_{to-heat}} \tag{4}$$

Although this methodology is not fully explicit (for instance, the unit ratios are not fully detailed), it provides access to a large and precise database, which motivated its selection. A comparison between the two methods was conducted but proved inconclusive due to the lack of data for the EPC-method. Building matching between databases was based on footprint overlap. Consumption estimates derived from EPC data—whether climate and altitude corrections were included or not—were on average 2.6 times higher than those estimated by Cerema.

This discrepancy is explained by the inherent limitations of EPC-based calculations, which provide only rough approximations of heat consumption and do not account adequately for climate or altitude. Furthermore, the comparison mainly concerns lower-consumption buildings (below 100 MWh/year), whose consumption is largely overestimated under the EPC method. Given these shortcomings and the loss of 90% of buildings, the Cerema databases were selected.

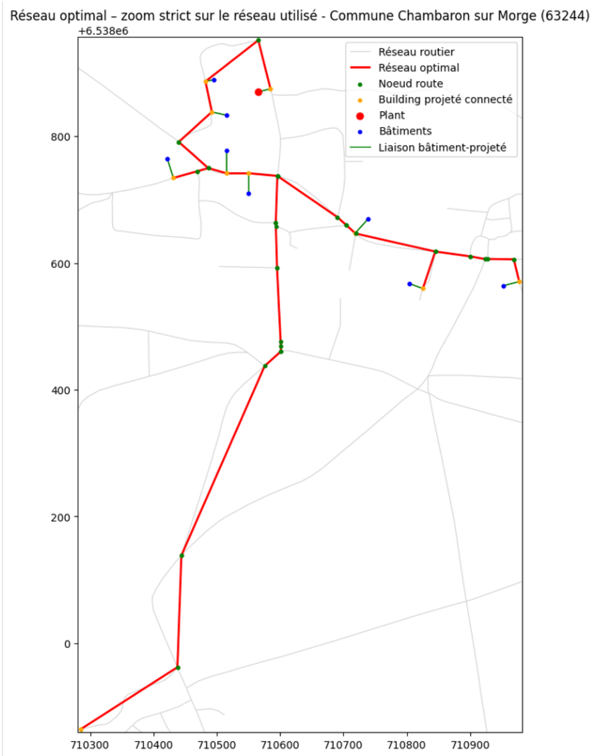

Figure 3: Zoom

3.3.2 Road Routing and Orthogonal Projection

Buildings are orthogonally projected onto roads. Pipes are assumed to run only beneath roads or along the orthogonal projection connecting a building to its nearest road.

Pipes are modeled as linear segments between "intersection points," defined as either road–road intersections or road–building projection intersections. Although this does not strictly follow the exact geometry of roads, the approximation is justified for two reasons:

- Pipes are typically installed in straight segments in practice.
- The dense mesh created by building projections onto roads significantly reduces approximation errors.

3.3.3 The 1.5 MWh.ml^{-1} $\cdot$ year^{-1} Criterion

Based on ADEME studies on district heating networks, a profitability threshold of 1.5 MWh per linear meter per year is adopted [2]. In his book on district heating networks [14], Guillaume Perrin suggests that this threshold may be lowered depending on municipal objectives (e.g., maximizing the number of connected buildings rather than profitability) and geographical context. Nevertheless, the reference value of 1.5 MWh.ml^{-1} $\cdot$ year^{-1} was retained in this study.

3.3.4 Energy Threshold and Municipality Filtering

A minimum thermal energy demand threshold was introduced to ensure network profitability. This threshold corresponds to a maximum instantaneous power of at least 30 kW, which, according to ADEME, distinguishes high-power networks [3].

$$P_{max} \geq 30kW$$

Using available databases, this power threshold was converted into an annual energy threshold. Data were available for three construction periods (before 1974, 1974–1989, and 1989–2005), allowing hourly thermal power calculations:

$$P = \rho \, c_p \, \dot{V} \, \Delta T$$

where ρ is water density, c_p its specific heat capacity, $\dot{V}$ the mass flow rate, and ΔT the temperature difference.

Buildings constructed during the same period are assumed to share the same consumption profile, scaled by floor area. The proportionality coefficient α is computed by dividing the maximum power by 30 kW and multiplying it by the annual energy equivalent of the curves. The maximum energy obtained among the three models defines the threshold used to filter buildings.

3.3.5 Small and Large Networks

By definition, a network must include at least two buildings. However, under our assumptions, profitability may still be achieved with very few buildings, which significantly increases computational time when testing all municipalities within a department.

Therefore, municipalities with strictly fewer than 10 buildings after energy filtering are excluded from algorithmic processing. Statistically, such municipalities are unlikely to yield viable networks, or would produce networks with very few buildings. Nevertheless, if the algorithm ultimately produces a network with fewer than 10 buildings, these are retained but classified as "small networks."

3.3.6 Optimal Location of the Power Plant

The choice of starting building strongly influences the resulting network. Initial modeling used the highest-consuming building as the starting point, since the decision criterion compares the ratio of total energy to total network length against a fixed constant. In dense municipalities, energy values typically outweigh distances. However, this assumption fails in more dispersed geographies or when the highest-consuming building is spatially isolated.

A study evaluating networks generated from each eligible building within selected municipalities showed that while the highest-consuming building is often a good starting point, it is not always optimal—or even viable (Figure 4). The same applies to the geographical center or the energy density center of the municipality.

The most effective solution is to test the N highest-consuming buildings as potential starting points and select the one maximizing the percentage of total municipal energy demand covered by the network. Choosing N involves a trade-off between optimality and computational time. A study conducted on 50 randomly selected municipalities across France showed that N = 4 provides a good (Figure 5):

- 50% of municipalities achieve the optimal solution,
- 75% achieve at least 92% of the optimal solution,

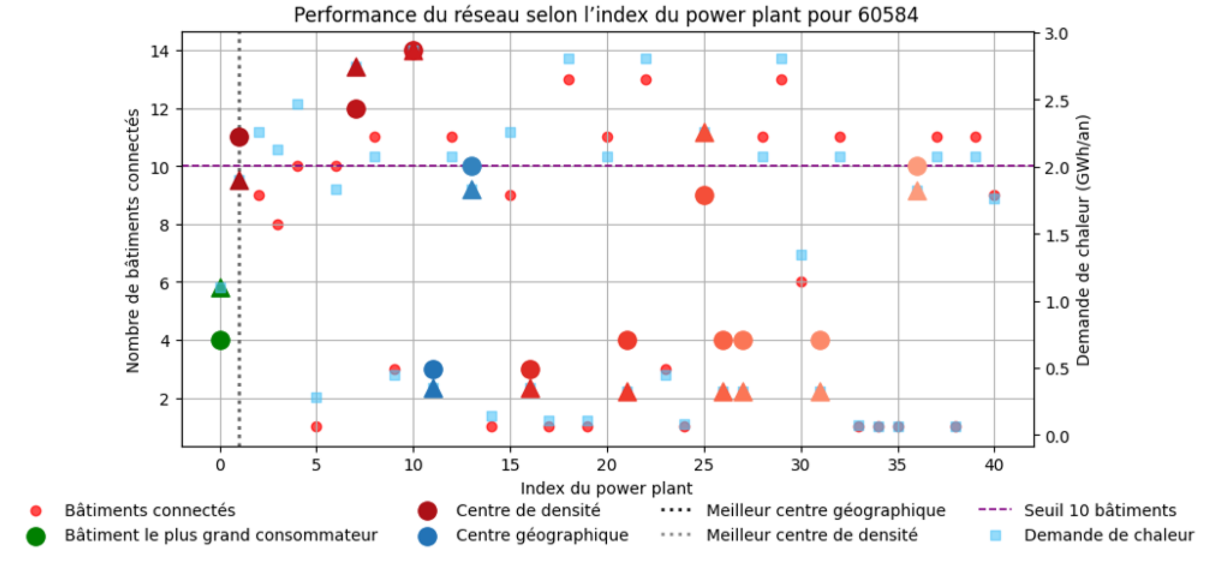

Figure 4: Starting building

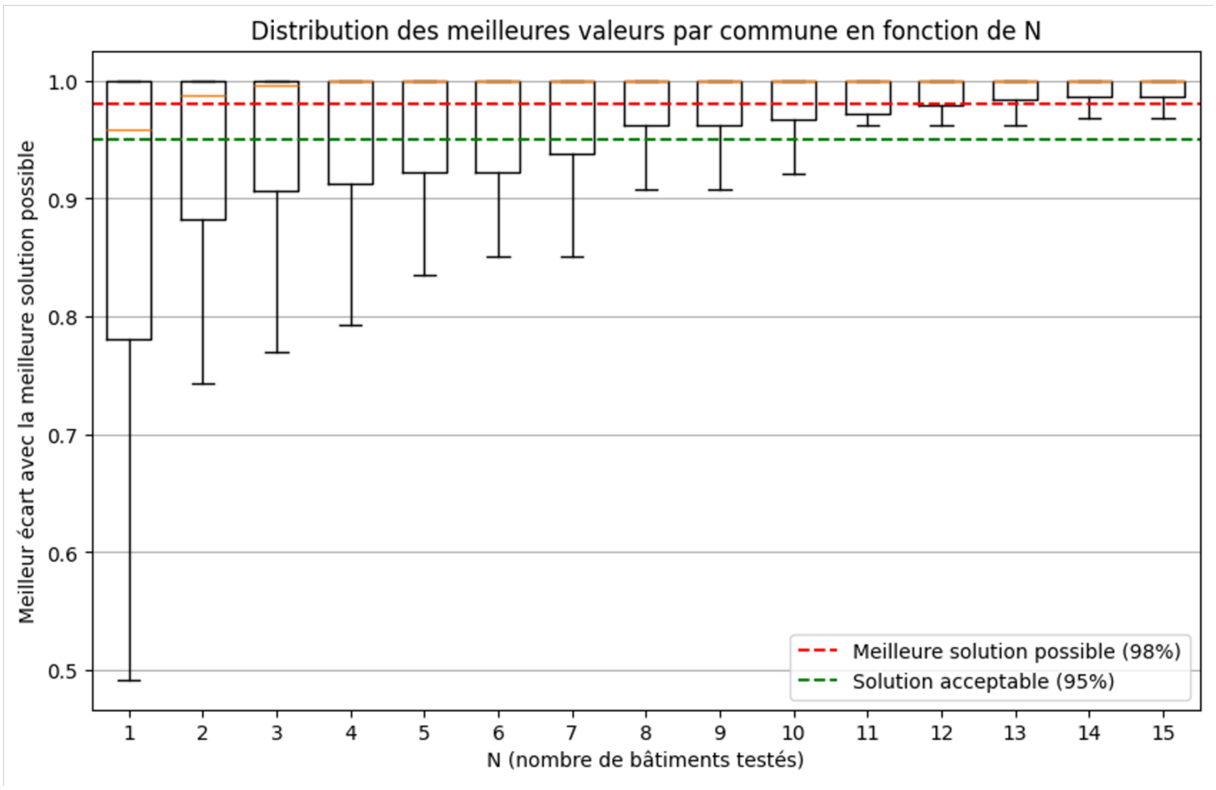

Figure 5: Boxplot of results

- 100% achieve at least 84% of the optimal solution.

For municipalities of particular interest, a refined study may run the algorithm starting from each building individually to identify the exact optimal configuration.

3.3.7 General structure of the code

- Preparation of databases in CSV format containing the coordinates of roads and buildings, along with their heating and domestic hot water consumption data.
- Selection of the municipality of interest / Iteration over all municipalities within a department.
- Stage 1 rejection if fewer than 10 buildings (very rare).
- Transformation of the buildings' coordinate system to match that of the roads.
- High-pass filter on maximum annual energy (58.35 MWh); Stage 2 rejection if fewer than 10 buildings remain.
- Geometric filtering of roads to retain only those crossing the municipality.
- Creation of listBuildings, with buildings as NodeBuilding objects sorted in descending order of energy consumption, and creation of listRoads.
  - Road–road and road–building intersections are represented as Node objects.
  - Neighbor relationships are retrieved for each node based on intersections.
- Testing of all necessary starting buildings ("power plants"):
  - Dijkstra's algorithm to compute building distances to the power plant and retrieve predecessors.
  - Attempts to connect buildings (see previous algorithm).
- If the number of connected buildings is strictly less than 2 → municipality rejected (Stage 3).
  - If fewer than 10 buildings → classified as a small network (Stage 4).
  - If 10 or more → classified as a large network (Stage 5).

4 Results

4.1 Local Scale

All municipalities from departments whose databases are available on GitHub can be tested using the notebook of LocalScale [11].

Dijkstra validation: The correct functioning of Dijkstra's algorithm is verified for computing distances along roads from all buildings to the power plant (starting building). (Figure 6)

Beauvais:

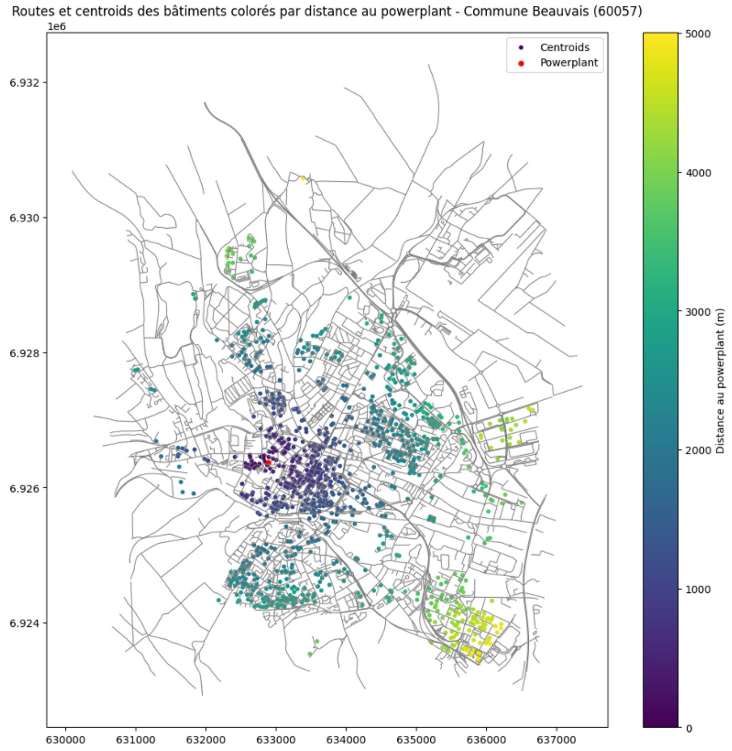

Figure 6: Validation of Dijskstra

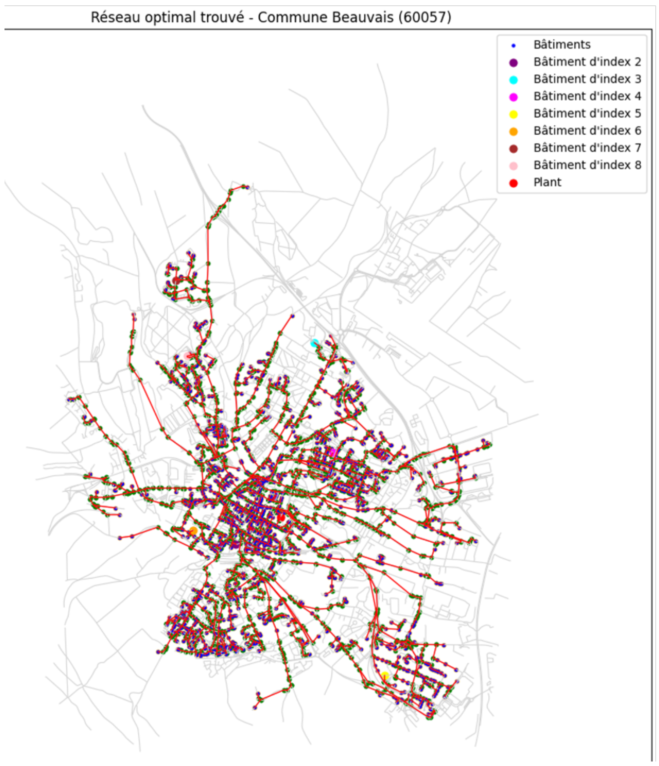

Figure 7: Beauvais

Networks can take very different shapes and vary significantly depending on the position of the starting building. If buildings are well distributed, the network may connect the extremities of the municipality and even all eligible buildings (Beauvais - Figure 7). Comparisons with existing networks often show substantial differences or only partial overlap. This can be explained by territorial, political, and social constraints, as well as different optimization approaches. (Figure 9)

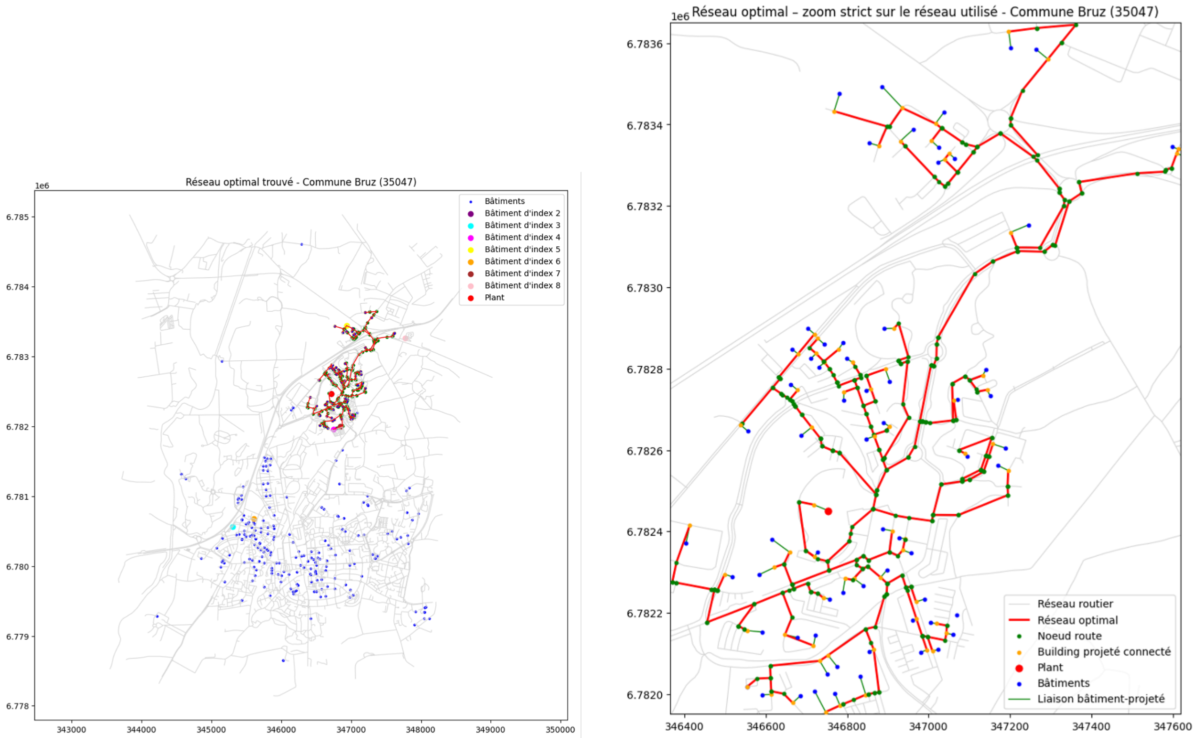

Figure 8: Comparison between Bruz and Bruz Zoom.

4.2 Departmental Scale

A diversity of profiles can be observed within a department. All municipalities per department are available in the repository, including buildings, roads, traced networks, separation between small and large networks, and network characteristics (Figure 10).

4.3 National Scale

A total of 8,295 eligible municipalities were identified, grouped into 3,220 large networks (at least 10 buildings) and 5,075 small networks. There is no fundamental difference between the distribution of large and small networks, except that all major cities have a large network, as do the surrounding relatively populated municipalities, while small networks are spread across the rest of the territory. The colors on the maps vary in intensity depending on the number of buildings included in each network.

The comparison with the Enrezo model [9], both for existing district heating networks and for those with potential, is consistent. The densest areas in our model correspond to those where actual district heating networks are found. It is also observed that, although the potential in Île-de-France and around Lyon is already fairly well exploited, the rest

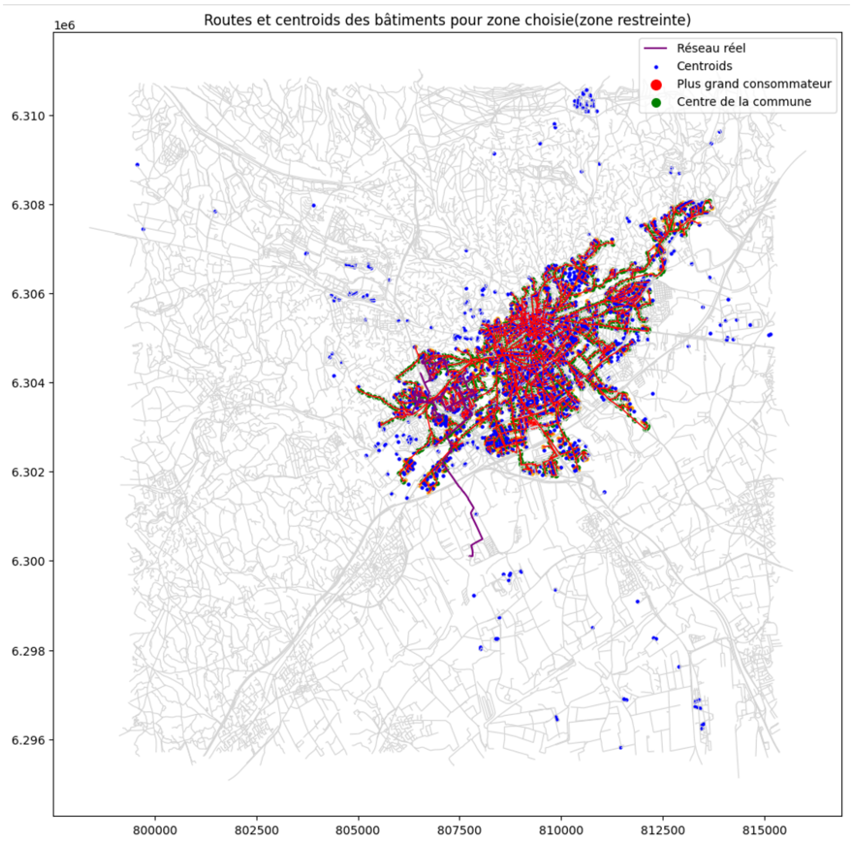

Figure 9: Nice modele and reel

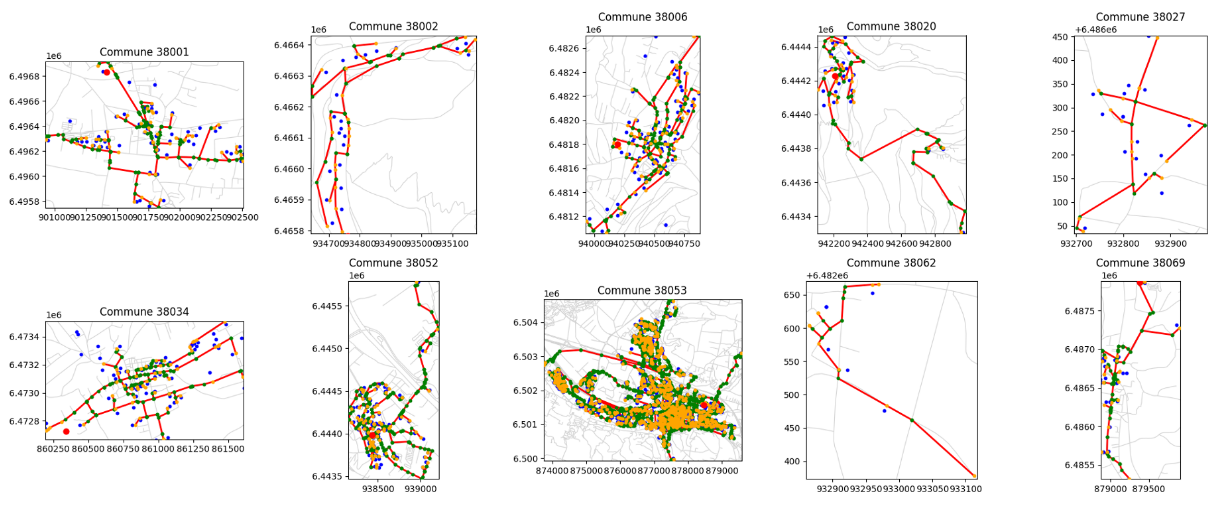

Figure 10: Departmental Scale

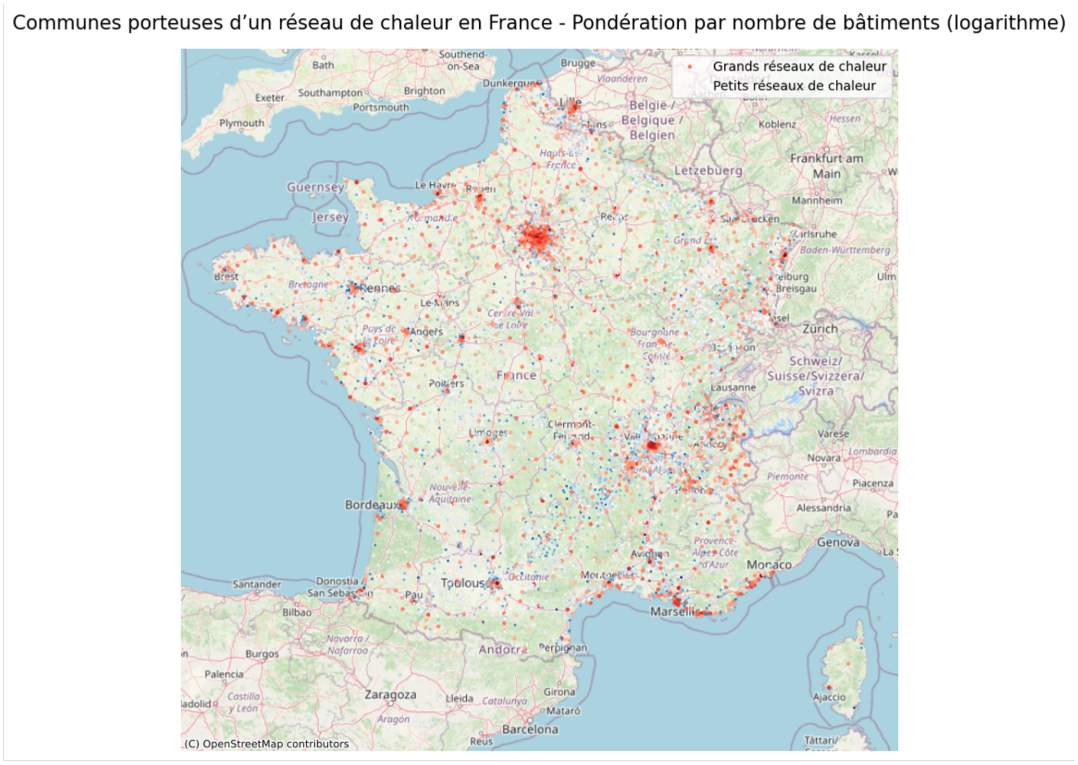

Figure 11: All Networks

of France—particularly the southern regions, the Grand Est region, and the Massif Central—shows largely untapped potential.

Overall, the same areas of potential and actual network development can be identified. However, our grid is more detailed.

Methodological Differences with EnRezo

Cerema's method for building EnRezo maps focuses on regional potential rather than real routing. EnRezo divides its areas into "high potential," with buildings consuming at least 300 MWh per year, and "potential," with buildings consuming between 100 and 300 MWh per year. The platform does not provide a network layout for these zones; instead, it aggregates the buildings of interest if they are sufficiently close (it allows a maximum distance of $d_2 = 250$ between buildings, given that their area was stretched by $d_1 = 185$m).Buildings deemed profitable are connected "as the crow flies," not along road networks—this is the key constraint in our approach.

Our model includes all buildings consuming more than 58 MWh per year and later distinguishes networks according to the number of connected buildings.

A comparative study was conducted between our model and the model underlying EnRezo, by region. EnRezo overestimates district heating potential in terms of regional energy compared to our model.

- Average and median gap: **+4.1 TWh per region**
- Minimum gap: **+0.1 TWh (Corsica)**

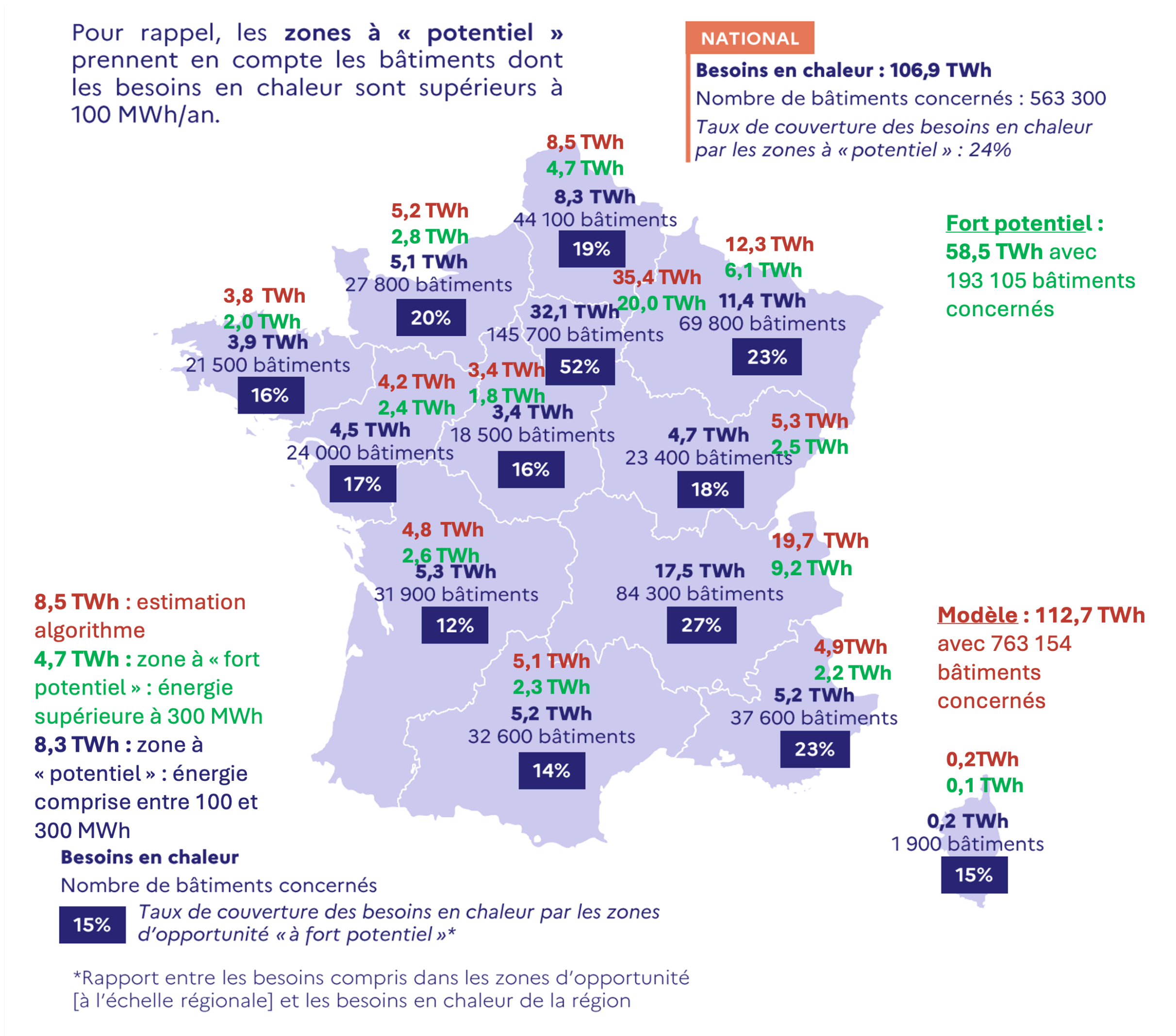

Figure 12: Regions

- Maximum gap: **+16.7 TWh (Île-de-France)**

Total EnRezo potential: **154.4 TWh with 756,405 buildings**.

Our model: **112.7 TWh with 763,154 buildings.**

The large discrepancy in Île-de-France is explained by extreme urban density, leading many areas to be classified as high potential. In practice, connecting buildings strictly within municipal boundaries—as done in our model—is more complex. This highlights the relevance of inter-municipal networks in such configurations.

Thus, our thermal coverage is lower despite including more buildings. Differences in thermal coverage are due to methodological differences, while the larger number of buildings in our case results from a lower energy filter threshold.

Their profitability threshold is more stringent (3 MWh per linear meter per year), but their building-connection test applies the energy of the candidate building divided

Figure 13: Enrezo's modele

by its distance to the source, rather than total energy divided by total graph distance after inclusion. This prevents connecting buildings far from the source, even if they are actually close to the existing network.

Table 1: Comparison between Cerema and our model for district heating network mapping

Criteria	**Cerema Model**	**Our Model**
Precision of network routing	Low (as-the-crow-flies)	Very high (roads + optimization algorithm)
Linear density constraint	High (3 MWh/ml)	Moderate (1.5 MWh/ml)
Building selection constraint	High (demand > 100 MWh for potential)	Moderate (demand > 58 MWh)
Selection methodology	$\frac{E_{\text{building}}}{d_{\text{building-source}}} \geq$ density; unrealistic star-shaped graph	$\frac{E_{\text{total}}}{d_{\text{total}}} \geq$ density; realistic network along roads

Statistical Observations

We plotted logarithmic-scale boxplots of the data aggregated at the national level, including network length (in km), heat supplied by the network (in MWh), the percentage of the municipality's heat demand covered by the network, the linear heat density of the network (in MWh per meter), and the number of buildings connected to the network. A distinction is made between large networks, small networks, and the total number of networks.

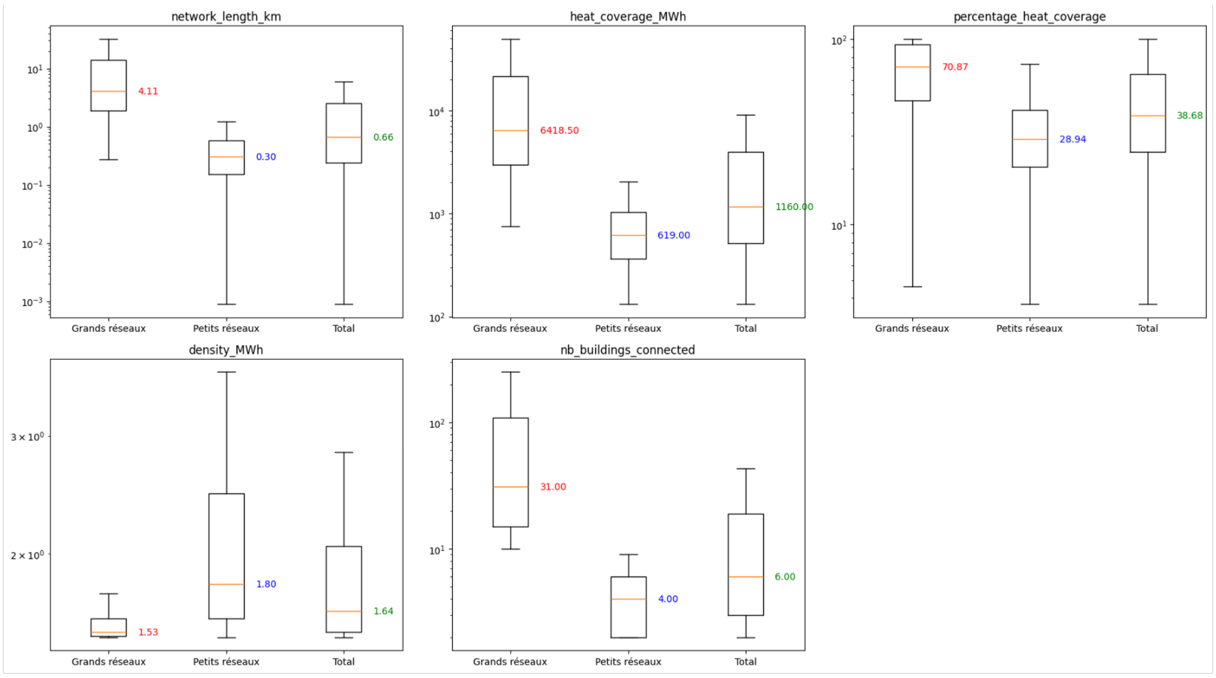

Figure 14: Boxplots

After removing extreme values for readability (Figure 14):

- Network length may reach $1,000$ km
- Heat coverage up to 1 TWh
- Density up to 140 MWh/ml
- Up to $100,000$ connected buildings

Large and small networks differ significantly in performance. Because small networks dominate numerically, aggregate statistics are closer to small-network performance.

The median energy density for large networks is extremely close to the 1.5 MWh.ml^{-1}.year^{-1} threshold, confirming the relevance of this limit.

On average:

- 70% of municipalities are rejected
- 64% of networks contain fewer than 10 buildings

Given the large number of French municipalities, this still represents a substantial number of potential networks.

Correlations We sought to establish correlations between the different characteristics of a municipality and the development of a district heating network within it. One particularly relevant question to address is: from how many eligible buildings can we be confident that a network will be established in the municipality ?

By plotting the correlation matrix (Figure 15) for the entire dataset, we observe that the number of eligible buildings is very strongly correlated with network length (in km),

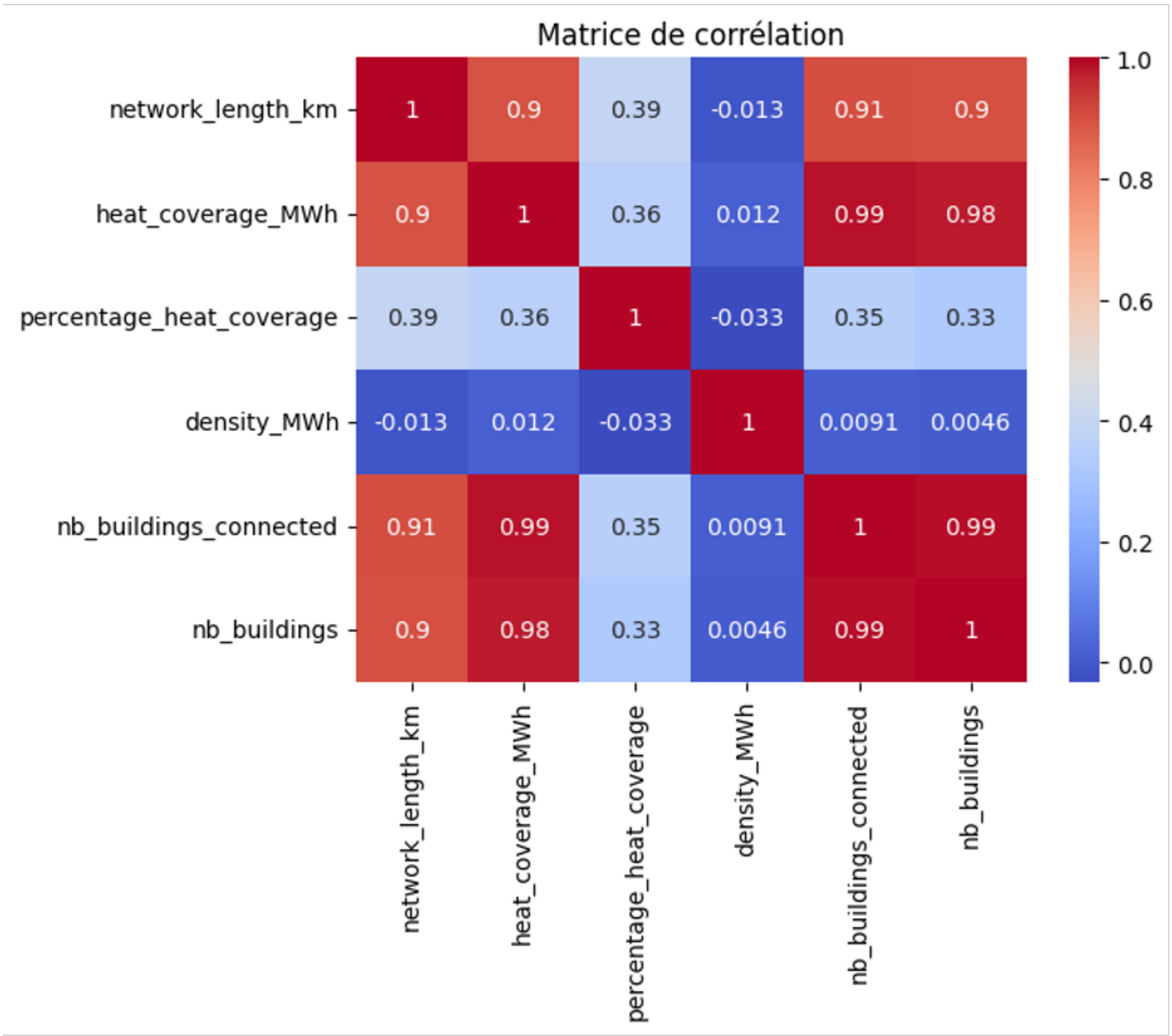

Figure 15: Correlation Matrix

the amount of heat supplied by the network, and the number of buildings actually connected to it. In other words, the more buildings a municipality has, the greater the number of connected buildings, as well as the network length and the quantity of heat supplied.

By contrast, we see that linear heat density is not influenced by any of the previously mentioned factors, as it depends too heavily on the structure of the network itself. The same applies to the percentage of heat demand covered by the network.

The number of eligible buildings is strongly correlated with:

- Network length (km)
- Heat supplied
- Number of connected buildings

However, energy density and percentage of heat demand covered are not significantly correlated, as they depend heavily on network structure.

Linear regressions show:

Connected buildings vs eligible buildings:
$R^2 = 0.98$
$y = x + 25$
$\rightarrow$ A municipality needs more than 35 eligible buildings to be certain of forming a large network.

Heat supplied vs eligible buildings:
$R^2 = 0.98$
$y = 20x$
$\rightarrow$ Adding 100 buildings increases network capacity by 20 GWh. $\rightarrow$ Average building demand = 200 MWh.

4.4 Comparison with Real Data

Compared with existing networks [13]:

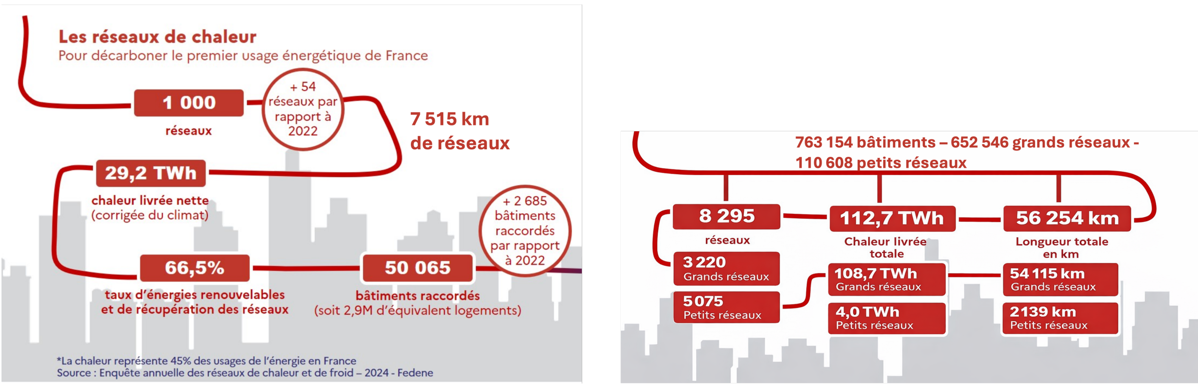

Figure 16: Comparison.

Clearly, full deployment is not immediately feasible. Municipal prioritization and financing strategies are required.

Using the 2024 report from Fedene, we carried out a region-by-region comparison. We note that the percentages of energy coverage are extremely close to those currently observed. This demonstrates the robustness of the model in terms of construction potential relative to existing networks. The share of regional heat demand covered is simply higher. The only significant decrease concerns Île-de-France, whose share drops from 40% (today) to 31% (model) of total national coverage. This can be explained by the already large number of district heating networks in this region and by the fact that our model develops many networks elsewhere, thereby reducing Île-de-France's relative share. Nevertheless, it remains by far the leading region in terms of consumption.

We conducted a more in-depth statistical analysis of these results by calculating the ratios of heat coverage, number of networks, and network length for the 13 regions of France, aggregating the results for Provence-Alpes-Côte d'Azur (PACA) and Corsica, as was done in the Fedene report.

Median regional ratios:

- Thermal consumption: 4.67
- Number of networks: 9.11
- Network length: 8.05

The smallest differences are observed for Île-de-France, for the reasons previously explained. The largest differences concern heat coverage and network length for the Provence-Alpes-Côte d'Azur (PACA)–Corsica grouping, due to the high potential of the Provence-Alpes-Côte d'Azur region and its relatively low level of coverage at present.

5 Discussion

Several assumptions warrant further examination:

- The 10-building threshold separating small and large networks is arbitrary.
- The 58 MWh energy threshold could be refined.
- The 1.5 MWh density threshold could vary by geography (lower in rural areas, higher in urban areas).
- Cerema data lacks transparency regarding unit consumption ratios.
- Power plant location should be distinguished from the first connected building.
- Inter-municipal networks could unlock additional potential.
- Technical feasibility and financing mechanisms require further study [15].

6 Conclusion

This study developed a methodology and algorithms capable of identifying potential district heating networks across all French municipalities, including their routing and characteristics, based on precise real-world data.
We identify 8,295 networks, 3,220 large networks and those represent 96.5% of theoretical heat delivered.

The results highlight the vast untapped potential of district heating in France, alongside an already well-developed and expanding existing network.
Given their economic, ecological, and energy sovereignty advantages, continued research in this field appears highly promising.

References

[1] Ademe, *Mutualiser les ressources*, Mutualiser les ressources

[2] France-Chaleur *France-Chaleur* Densité

[3] Cerema, seuil de 30kW *Cerema* Cerema 30kW

[4] BDTopo BDTopo

[5] Cerema Bases de données Cerema

[6] Rémi Patureau, Cong Toan Tran, Valentin Gavan, Pascal Stabat, *The New Generation of District Heating and Cooling Networks and their potential development in France.* Center of Energy Efficiency Systems, Mines Paris PSL. Article

[7] Méthodes Calculs Cerema Méthodes

[8] Cerema note méthodologique Note méthoologique

[9] Cartographie EnRezo EnRezo

[10] Charlotte Gressel, *Assessing High-Potential Areas for the Development of District Heating Networks in France*

[11] GitHub GitHub

[12] Cerema, zones d'intérêt EnRezo bilan Bilan EnRezo

[13] Rapport Fedene 2024 Rapport Fedene

[14] Guillaume Perrin and Manon Leyendecker, *Les réseaux de chaleur*, édition Dunod 2021

[15] Estimation des coûts : Estimation des coûts