Ref. Ares(2024)8814609 - 10/12/2024

COOLING DOWN

Economic and technical Report

Identification of competitive advantages and barriers of renewable cooling: economics of renewable cooling, including a cost benefit analysis and recommendations for stakeholders

Deliverable number: D4.1

Author(s): AFPG, EGEC

Project Full Title:	COOLING DOWN
Project Acronym:	COOLING DOWN
Grant Agreement No.	101077140
Title:	Deliverable 4.1 - Economic and technical Report
ORCID:	

Approval status			
	Name	Function	Date
Deliverable responsible	**AFPG**	Draft by Task leader	17/10/2024
WP leader	**AFPG**	Validation by WP leader	17/10/2024
Review by partners	**all**	Comments by partners	28/11/2024
Final Version by project coordinator and WP leader	**EGEC, AFPG**	Validation	03/12/2024

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Introduction

The Cooling Down project is designed to address the growing demand for cooling solutions while promoting the adoption of renewable and energy-efficient technologies across Europe. As cooling becomes an essential need, especially in light of increasing heatwaves and rising temperatures, the project aims to facilitate the decarbonization of the cooling sector by advancing renewable technologies that align with the European Union's climate and energy objectives. The overarching objectives of the Cooling Down project focus on accelerating the market uptake of renewable cooling technologies, improving their competitiveness, and ensuring that investments in the sector are directed toward sustainable solutions. Additionally, the project addresses a critical data gap in understanding cooling demand and supply, particularly for renewable cooling production, and seeks to bridge this knowledge gap by providing comprehensive insights into these areas. The project also aims to promote solutions that integrate renewable cooling technologies with the broader goals of energy efficiency, greenhouse gas reduction, and the decarbonization of Europe's building stock by 2050.

A key feature of the Cooling Down project is its focus on reducing energy poverty linked to cooling, particularly for vulnerable households that may face barriers to accessing modern cooling technologies. The project aims to propose solutions that ensure these households are not left behind in the transition to a decarbonized energy system. By mainstreaming renewable cooling technologies, the project intends to contribute to the resilience of cities facing extreme climate impacts, such as heatwaves, while minimizing the urban heat island effect through energy-efficient cooling systems. Finally, the project seeks to bridge the gap between various stakeholders in the cooling sector, including policymakers, decision-makers, investors, and building professionals, ensuring that they have access to reliable data, insights, and innovative business models to facilitate the widespread adoption of renewable cooling solutions.

Highlight of work package four (4)

WP4 focuses on the business models and project funding for renewable cooling solutions, specifically looking at the economic and technical feasibility of geothermal and solar cooling technologies. Key activities include:

Task 4.1: Identifying competitive advantages and barriers for renewable cooling solutions. This includes a cost-benefit analysis between geothermal, solar thermal, and other cooling solutions, targeting different stakeholders like energy providers, public bodies, and end-users.

Task 4.2: Developing innovative business models to facilitate the market uptake of these cooling technologies. This involves analyzing existing business models and adapting them to the renewable cooling sector.

Task 4.3: Developing of Political recommendations based on the results of the technical-economic models developed in previous tasks to stakeholders, and actors involved in the regulation of buildings – including the design of financing schemes public or private – in order to address barriers to the uptake of relevant renewable and efficient cooling solutions

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General remarks

Supposedly, the main hypothesis is that the extensive use of electrical solutions for heating (air-source heat pumps..) could generate important externalities for energy providers as manager of electrical grids.

This perspective explored further was as follows. The “reference” solution being active cold by aerothermal heat pumps:

1/ Should the electricity network be reinforced to cope with power surges, whether in winter (for heating) or in summer (for cold)? Would such a reinforcement include electrical storage?

2/ Should new power plants be built to cope with this increase in power and energy needs?

This possible “energy provider” externality was studied in the first “case study” (Paris) and abandoned in view of the results obtained. Therefore, it is mentioned at the end even if its role it is not quantified.

As an explanation, an RTE study1 showed that the conversion of current systems to heat pumps (aerothermal or geothermal) would not pose any problems. This is because electric heating is very developed in France. Indeed, the electricity network is fully capable of absorbing the electrical peak resulting from the even rapid conversion of fossil gas uses into electrical uses. As a result, this “energy provider externality” has been considered as not valuable for the Paris’ case.

However, a study2 has been identified which compares the advantages of geothermal and aerothermal energy in the United States (November 2023). It estimates that the economic effect could be significantly greater on the costs of consolidating the electricity network than on the savings for the user. This would also lead to a reduction in the cost of an electric MWh for all users (not just those equipped with geothermal energy), while the generalization of aerothermal energy would increase them.

Summary of the methodology:

1. After having established for each type of building the associated costs.
2. The total cooling needs of a given city and how they are shared among each kind of building have been estimated. Heating needs were also included in the comparison.

	Individual house	Collective (residential) building	Office	Commercial center	Health facility
Assumed cooling need in basin (GWh/y)			**3044**		
Percentage of cooling needs	**2%**	**6%**	**48%**	**28%**	**16%**

3. The total costs for installations, energy and maintenance (H&C) for the city have been calculated.

[1] Pages 7 and 8: https://www.afpac.org/attachment/2583761/
[2] https://info.ornl.gov/sites/publications/Files/Pub196793.pdf

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4. The cost of 2 externalities due to cooling have been estimated: productivity loss and mortality.

	Recommendations for geothermal energy
Type of buildings	1- Residential 2- Collective buildings 3- Offices 4- Shopping malls 5- Health facilities
Costs (2021, 2022)	Studies, drilling, connexion, HP and its installation, exploitation
Performance	COP, EER and EER/cooling
Cost of energy	National tariff by the main energy providers
Support schemes	French schemes: MaPrime Rénov => residential market Heat Fund => all other sectors

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Part I _ Techno-economic comparison's analyse

A market analysis has been conducted, assessing the current state of renewable cooling technologies like geothermal cooling. This involved identifying competitive advantages and market barriers, as well as analyzing the regulatory landscape and economic incentives. Data was gathered from existing studies, reports, and stakeholder consultations from experts in Italy, France and Romania to understand the market dynamics and acquire data.

Next, a cost-benefit analysis was executed to compare the financial and technical feasibility of geothermal solutions with traditional options (which is the reference solution and includes gas boiler for heating and air/air heat pump for cooling). This includes evaluating life-cycle costs, operational expenses, and potential savings, as well as the environmental and social benefits, such as reduced emissions and energy efficiency gains.

Preliminary note:

Certain methodological choices arise from part II, and more particularly from the quantification of certain effects. For example, some externalities were not included in the final methodology, as their effect was only very marginal and within the margin of uncertainty of other externalities.

That was the process to tackle the issue:

1. Focusing on one major city in each country, with an estimation of the cooling needs and the type of building that uses it.

2. Description of these typical buildings, and estimation of the the number of such typical buildings in the city. A comparison was made per typical building between "typical solutions" and "geothermal heating and cooling". An economic balance was deduced for the user when an efficient geothermal solution is used both for heating and for cooling.

3. Taking into account externality costs.

Part II justifies that the externalities retained are those dealing with productivity losses and mortality. An Austrian study provides the way to quantify them.

However, it was necessary to retain a sufficiently simple hypothesis on the reduction of the "heat island" effect, insofar as this is only partly linked to the effects of air conditioning and the hypotheses taken on the other causes are likely to modify the effect attributable to air conditioning alone. This is why it was assumed that only half of the economic effects linked to exposure to heat islands could be avoided.

The choice was made not to consider the effects on electrical networks, to the extent that it appears not to be problematic in France (see above, RTE study) and that a robust methodology could not be found nor the necessary data per country to apply such a methodology.

Finally, the choice was made to look at "individual" solutions: the economic results would be even more interesting with optimizations such as "establishment of geothermal networks" when

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the cost of these networks is lower than the sum of the costs. individual solutions for the areas served.

1-1-Methodology and energetic needs hypothesis:

In order to estimate the costs of geothermal installations, it is essential to select representative building types for which the energy requirements are known. Since our study aims to highlight the role of geothermal energy in the field of air conditioning, it is also important to take into account the heating and domestic hot water needs in order to design a suitable system and compare it to other heating and air conditioning installations.

For the residential sector made up of 37.2 million dwellings of approximately 460 million m2[3] the energy needs of an individual house and a collective dwelling will be estimated. As for the tertiary sector which includes several sub-sectors of activity, the study focuses on three types of buildings identified in the ADEME report “Air Conditioning in Buildings” published in 2021, as representing the largest air-conditioned surface area. and also the highest energy consumption[4] These sub-sectors include the office sector, retail and healthcare establishments.

Housing and collective buildings

The heating and cooling needs for residential housing largely depend on the quality of the building envelope and its thermal characteristics, and these needs vary massively depending on the location of the housing. Indeed, the RT2012 thermal regulation has established 8 climatic zones according to temperatures in winter (H1, H2, and H3) and summer temperatures (a, b, c and d).

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3 INSEE. Le nombre de logements. 2021
4 ADEME. La Climatisation dans le bâtiment. 2021

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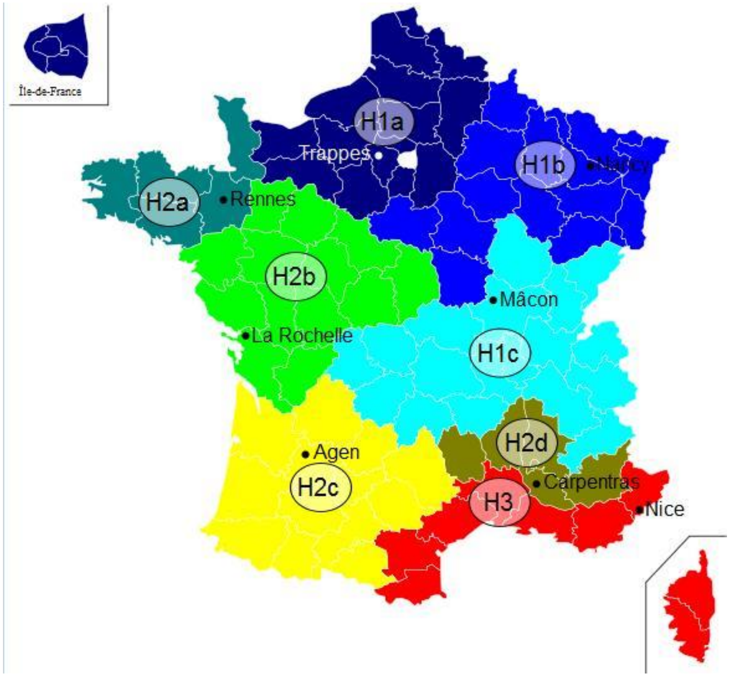

Figure 1 Climatic zones in France

This is one of the reasons why it was decided to focus on a given city (Paris in this case), where one single climate can be a good assumption.

Following the analysis of several documents on the needs and consumption of housing as well as the powers of heat pumps sold in the residential sector, and after discussions with a committee of professionals, the following characteristics were retained:

	Single family house	Multifamily house
Surface	100 m^2	1 000 m^2
Heating needs (Heating + DHW)	12 MWh/an	100 MWh/an
Heating power	7 kW	50 kW
Cooling needs	2 MWh/an	18 MWh/an
Cooling power	5 kW	30 kW

Table 1: characteristics for residential buildings

Offices

The office sector is the tertiary sub-sector that consumes the most energy, with a total surface area of more than 243 million square meters and an annual energy consumption of more than

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33 TWh[5] Heating and domestic hot water needs are similar for offices to air conditioning needs, as are the power requirements.

Offices come in different sizes, ranging from small agencies to buildings of less than 1000 square meters, areas between 1000 and 5000 square meters, as well as buildings of more than 5000 square meters. Based on their distribution, the weighted surface area of a typical office is presented in the table below, along with other relevant data.

	Office
Surface	2 400 m^2
Heating needs (Heating + DHW)	155 MWh/an
Heating power	110 kW
Cooling needs	140 MWh/an
Cooling power	110 kW

Table 2: characteristics for offices

Shopping centers

Shopping centers are special establishments because they have both heating and cooling needs to ensure occupant comfort, as well as specific active cooling needs for uses such as refrigeration. Their heating and cooling needs are similar in terms of power and energy consumed. In addition, their industrial needs are estimated at around 480 kWh/m2.

	Shopping centers
Surface	3 500 m^2
Heating needs (Heating + DHW)	420 MWh/an
Heating power	110 kW
Cooling needs	420 MWh/an
Cooling power	110 kW
Active cooling needs (process)	1 670 MWh

[5] OID. Le Baromètre Performance Énergétique et Environnementale des Bâtiments. Observatoire de l'Immobilier Durable; 2019.

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Active cooling power (process)	190 kW

Table 3: characteristics for shopping centers

Health care institutions

For this study, a residential establishment for dependent elderly people (EHPAD) was selected as an example of a health building. The energy data from an example of an EHPAD powered by geothermal energy[6] are presented below.

	Hospital
Surface	4 240 m^2
Heating needs (Heating + DHW)	260 MWh/an
Heating power	185 kW
Cooling needs	24 MWh/an
Cooling power	185 kW

Table 4: characteristics for health care facilities

1-2-Methodology and hypothesis on costs and efficiency

Cost assumptions

The part relating to the investment of geothermal projects mainly includes the costs of feasibility studies (geothermal study and thermal feasibility study), drilling and connection, heat pump and its installation, as well as costs annual maintenance. It is important to emphasize that these costs can vary considerably due to several factors, which can make the geothermal solution more or less economically interesting from one project to another.

Whatever the nature of the envisaged operation and the geothermal power sought, it is recommended to call on the expertise of a design office specializing in thermal (for the surface part) and geosciences (for the part below the ground). This will make it possible to choose the most appropriate geothermal solution taking into account the specificities of each project.

As part of this study, two geothermal solutions are considered: vertical geothermal probes (equally known as borehole heat exchanger - BHE) and aquifer geothermal energy, also called groundwater geothermal energy. However, it should be noted that there are other solutions available for residential installations that can meet heating and cooling needs.

As mentioned previously, the costs associated with these solutions can vary significantly. Drilling costs, for example, can differ depending on the type of rock drilled, depth, flow rate,

[6] Le Journal des énergies renouvelables. Établissement d'hébergement pour les personnes âgées dépendantes ou autre établissement de santé. 2023

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and region, with variations that can range from one to two. This wide disparity in costs makes it essential to conduct a thorough analysis to estimate the costs of proposed facilities.

For this reason, in addition to collecting the various operating costs by soliciting stakeholders in the sector, an analysis was carried out on the geothermal projects on probes and on groundwater supported by the Heat Fund – a system of the French State, managed by ADEME, which finances the development of renewable heat production. This analysis made it possible to evaluate the costs of installations in the tertiary sector (office, shopping center, nursing home), because they meet the criteria of the Heat Fund. These criteria require a minimum production of 25 MWh/year for installations on probes, and 25 or 50 MWh/year for installations on groundwater (depending on the year of submission of the application).

The costs analyzed correspond to projects carried out during the years 2021 and 2022. This choice is linked to significant changes in energy prices and the level of inflation compared to previous years. Fluctuations in energy prices and the impact of inflation can have a significant influence on the costs of geothermal projects. Therefore, it is essential to consider current market conditions when analyzing and evaluating geothermal projects. For statistical reason, it was not possible to focus on the costs in Paris only.

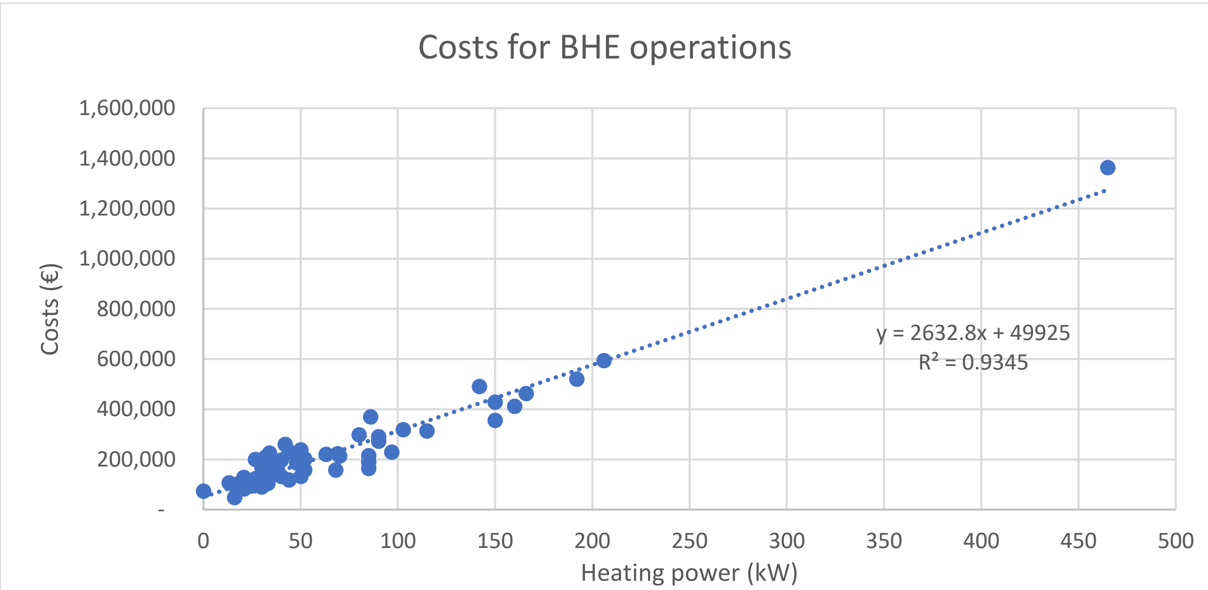

Figure 2 Borehole (probes) project costs and installed capacity

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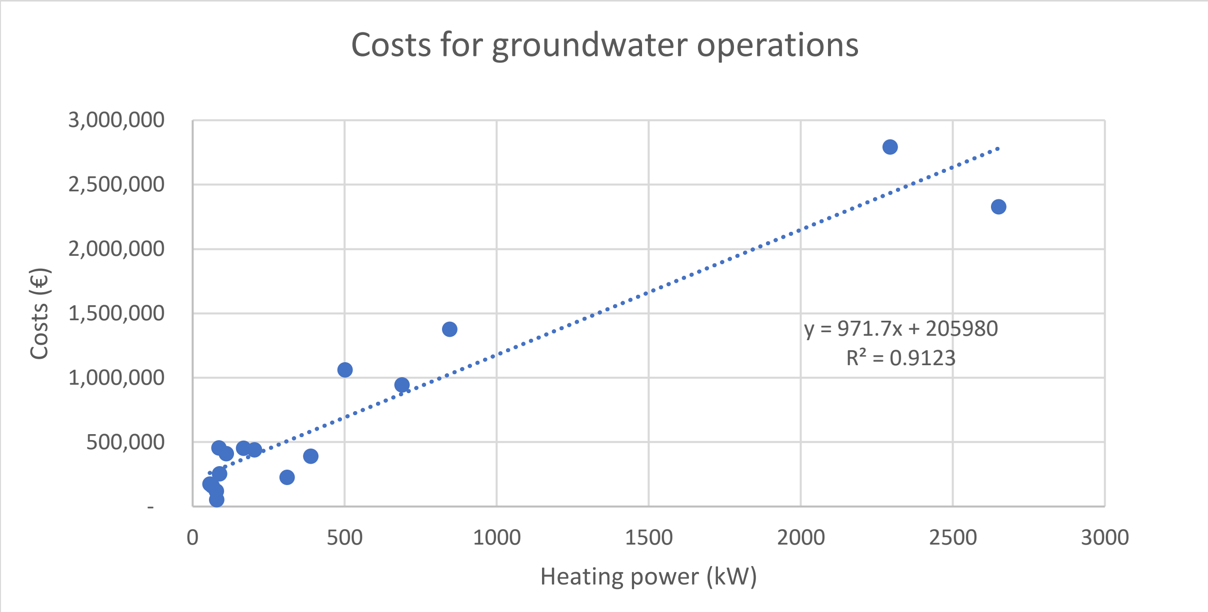

Figure 3 Aquifers project costs and installed capacity

Efficiency assumption

The coefficient of performance (COP) of a heat pump is the ratio between the useful or returned energy and the energy consumed, which is electricity in this case. This is an important indicator for evaluating the performance of the heat pump in heating mode. The higher the COP, the more efficient the heat pump is and able to produce heat from a reduced amount of electrical energy consumed.

Furthermore, the EER (Energy Efficiency Ratio) is the ratio between the useful energy or heat absorbed and the energy supplied to the heat pump. It measures the performance of the heat pump in terms of cooling. A higher EER indicates that the heat pump can absorb a greater amount of heat using a given amount of electrical energy.

Finally, the concept of geocooling was introduced. This is the use of the natural coolness of the ground for the direct cooling of a building by bypassing the heat pump when the ground conditions allow it. The operation of the geocooling is ensured by a low-consumption circulation pump allowing high performance in terms of operation. In this study, it is considered that cooling by geocooling provides 80% of the cooling needs for the residential sector (house and apartment) and 50% for the tertiary sector.

The operating assumptions used in this study are listed in the table below. These assumptions are based on consultations of product sheets from the main suppliers of heat pumps on the market, in accordance with standard EN 14511.

Performances	BHE	Aquifers
COP (B0/W35)	4,5	-

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COP (W10/W45)	-	6[7]
EER (B20/W7)	6	-
EER (W20/W7)	-	7
EER - Geocooling	30	30

Table 5 : Geothermal heat pump efficiency ratios

The lifespan of geothermal systems in the basement must be 50 years or more when the design stages are carried out in accordance with NF EN 17522. With regard to aging tests, professionals often estimate that this lifespan should be greater than 100 years: to our knowledge, geothermal probes were not yet installed a century ago, which is why this hypothesis cannot be confirmed by observation. Regarding heat pumps, their average lifespan is estimated at 26.7 years, with a standard deviation of 4.7 years according to a study in Switzerland. Therefore, as part of this study, geothermal and alternative solutions will be studied over a period of 25 years, without taking into account the renewal of the installations during this period. This value will make it possible to simplify the “LCOE” analysis, the approach of which will be carried out over 50 years.

Alternative solutions assumption

The alternative solutions were selected in order to be able to compare the performance and costs of geothermal installations with those of solutions commonly used on the market.

In the residential sector, 62% of homes are heated by non-electric solutions according to an RTE report on consumption in this sector[8] This study took into account the use of high efficiency gas boilers (98%) for heating, as well as packaged air conditioners for air conditioning.

For the offices, a roof unit system (rooftop) was chosen to provide both cooling and heating. In addition, a rooftop system associated with a gas boiler was selected to meet the needs of the nursing home for hot and cold, as well as for domestic hot water (DHW).

Regarding the shopping center, the heating and air conditioning needs are met by a rooftop system while for the active cooling needs, a chilled water unit was used.

The performance data of the chosen equipment is based on the examination of the technical sheets of the different options available, knowing that they meet the specific needs of each case. This approach ensures that the performance data used in this study reflects the actual capabilities of the selected equipment.

Performances	Monobloc AC	Rooftop system	Chiller
COP (A7-A35)	-	3,3	-

[7] This value does not include the electrical need of the groundwater pump.
[8] RTE. Groupe de travail « consommation d’électricité ». 2019

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EER	2,8	2,9	2,9

Energy prices

The tariffs used in this study correspond to the tariffs offered by the main market players in 2023. It should be noted that these tariffs were established after the significant increases in gas and electricity prices, notably due to the conflict in Ukraine. And for all contracts chosen, the off-peak hours option is taken with a distribution of consumption of 60% during peak hours and 40% during off-peak hours.

In this study, electricity subscription costs have been omitted because they are independent of the chosen solution. This allows a greater focus on the variable and specific costs of implementing geothermal solutions.

In addition, inflation in energy and maintenance costs was taken into account in all study simulations. The values used for this inflation are +4% per year for energy costs and +1% per year for maintenance costs. These annual increases help account for the impact of inflation on operational costs over time.

Energy prices	Single-family house	Collective building	Offices and hospitals	Shopping center
Tariff « heures pleines » (€/kWh – tax included)	0,2228	0,2228	0,1801	0,40278
Tariff « heures creuses » (€/kWh – tax included)	0,1615	0,1615	0,1433	0,22423
Gaz subscription (€/year)	250	113		
Gaz (€/kWh)	0,1054	0,1054		

Table 6 : energy prices

Support schemes

The aid taken into account in this study is MaPrimeRénov for the installation of a geothermal system in homes, and the Heat Fund for installations in collective apartments and tertiary buildings.

For the single-family building, it is considered that the household has intermediate income, which entitles it to assistance of €5,000 according to MaPrimeRénov.

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For Heat Fund assistance, all proposed installations meet the required criteria, such as minimum production of renewable energy, a minimum number of hours of operation at nominal power and a minimum COP. The aid rates over 20 years are presented in the table below:

Subsidies over 20 years	BHE	Aquifers
Heating (€/MWh EnR/year)	50	25
Cooling (€/MWh EnR/year)	13	13
Cooling with geocooling (€/MWh EnR/year)	13	13

Table 7: French Heat Fund support scheme ratios

1-3-Comparisons

In this part, the cumulative costs of geothermal solutions and comparison solutions are presented over a period of 25 years. These costs correspond to both initial investment costs and operating costs, which include electricity or gas consumption as well as maintenance costs. The objective is to evaluate the total costs of the different options over a significant period in order to be able to compare their long-term profitability and thus establish the moment when the profitability threshold is reached.

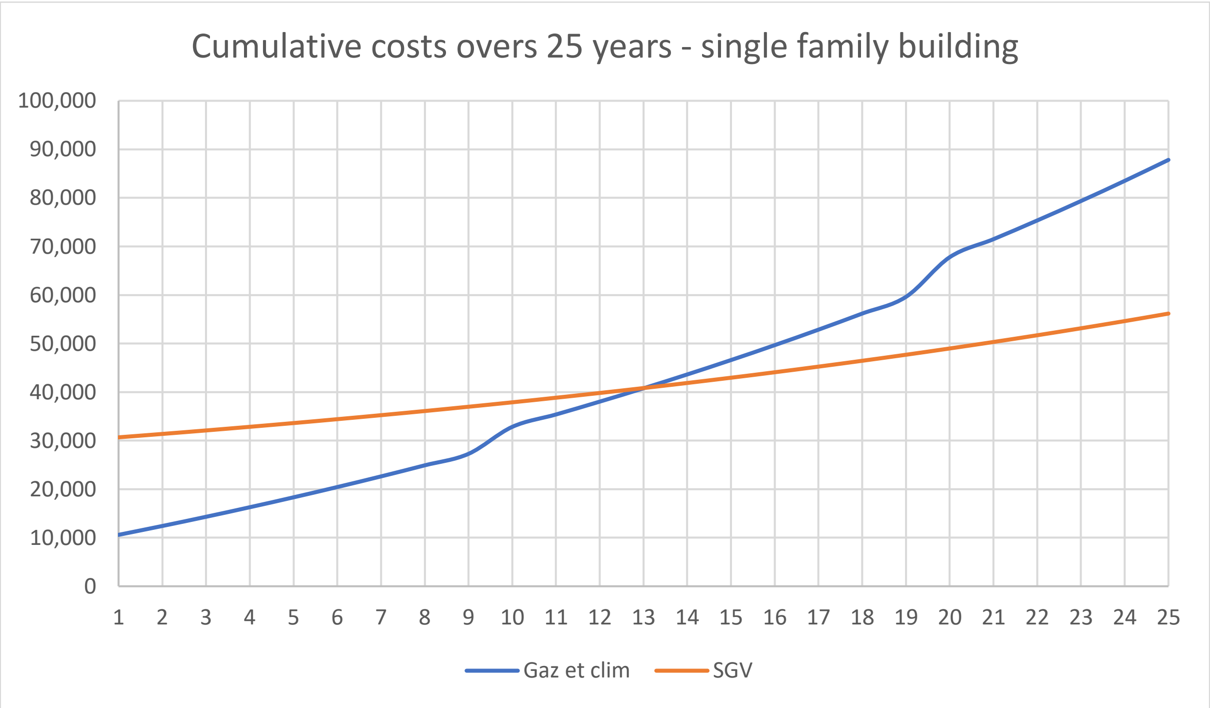

Figure 4 Cumulative costs for an individual house

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In the case of a detached house, the solution of geothermal probes becomes more profitable than the solution of a gas boiler and two packaged air conditioners after 13 years. The dropouts every 10 years for the gas/air conditioning solution are due to new investments for air conditioners. Over the lifespan of the geothermal system, mainly the heat pump (taken here at 25 years for practical reasons, see above), the direct savings can amount to nearly €30,000, an amount greater than the cost. replacement of the heat pump. This highlights the long-term economic benefits of using geothermal energy for heating and cooling a single home.

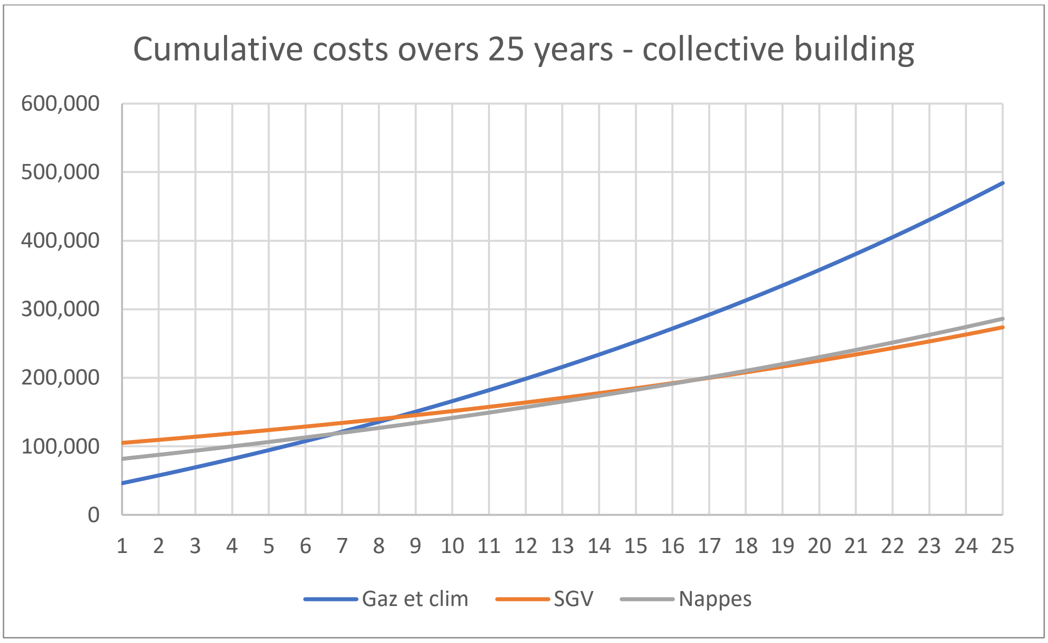

Figure 5 Cumulative costs for a collective building

Geothermal solutions become more profitable than the alternative solution after only 7 years for the groundwater geothermal solution and 9 years for the geothermal probe solution, which represents a considerably reduced duration.

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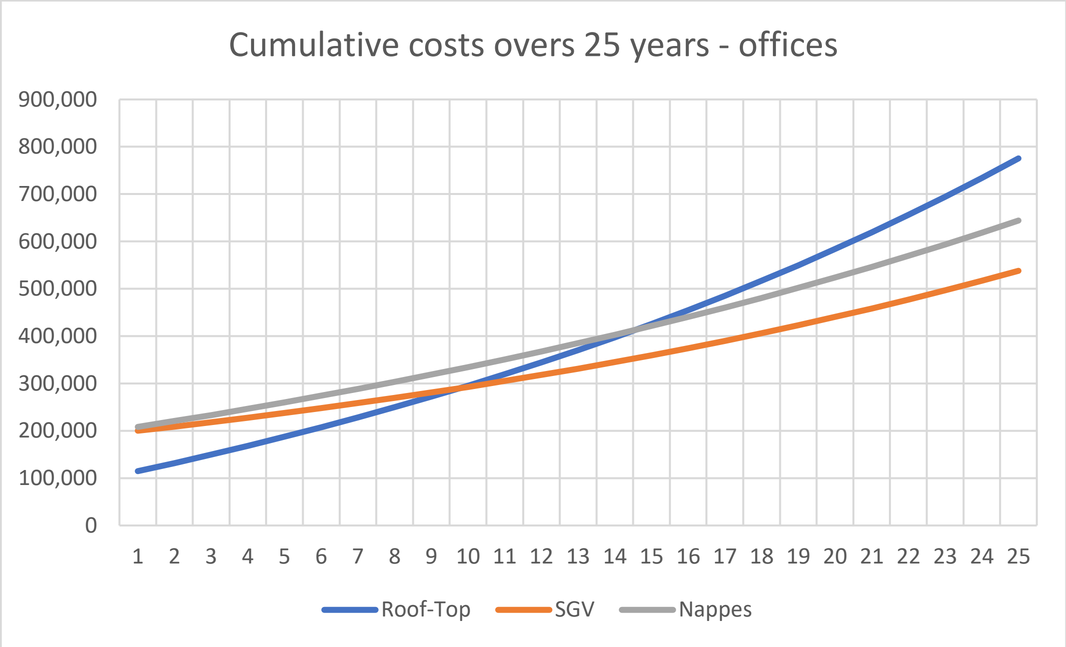

Figure 6 Cumulative costs for offices

Both geothermal solutions offer a cost-effective alternative to the comparison solution. After a period of 25 years, the geothermal probe solution saves up to €230,000 compared to the comparison solution, while the aquifer geothermal solution saves up to €130,000. In this case again, these amounts are higher than the cost of replacing the heat pump. These significant savings highlight the long-term financial benefits of using geothermal as a heating and cooling solution.

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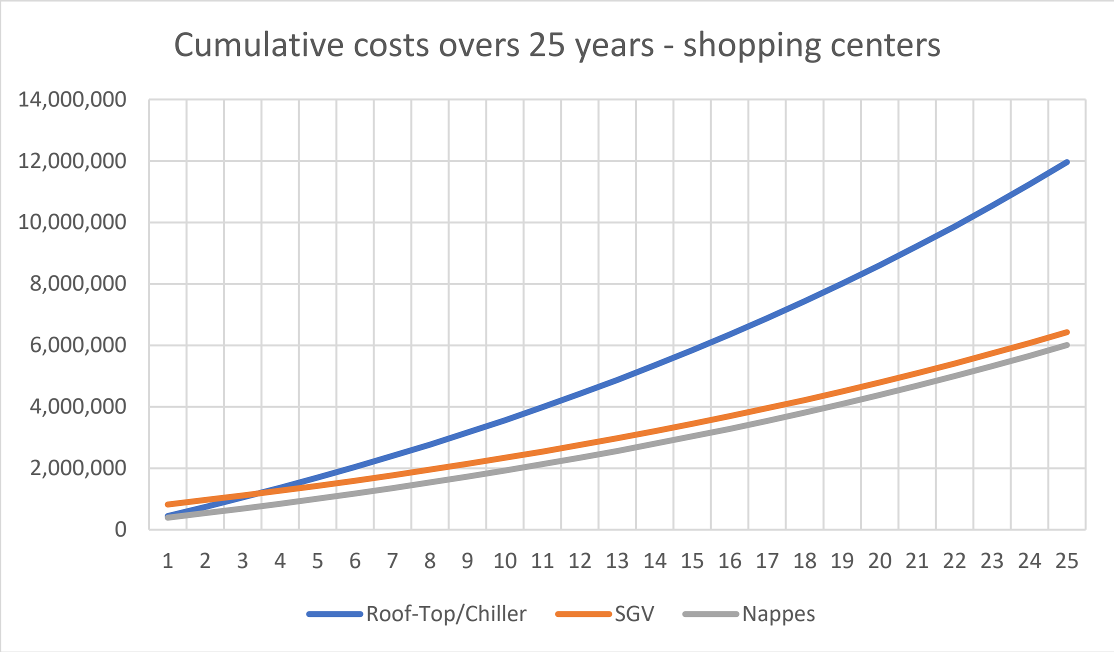

Figure 7 Cumulative costs for shopping center

The savings from using geothermal energy are considerable, representing almost half the cost of the alternative solution. This is particularly notable in the case of a shopping center, where the cooling demand is high. With a geothermal installation, cooling costs are significantly reduced, especially with an aquifer geothermal solution if available at the shopping center location.

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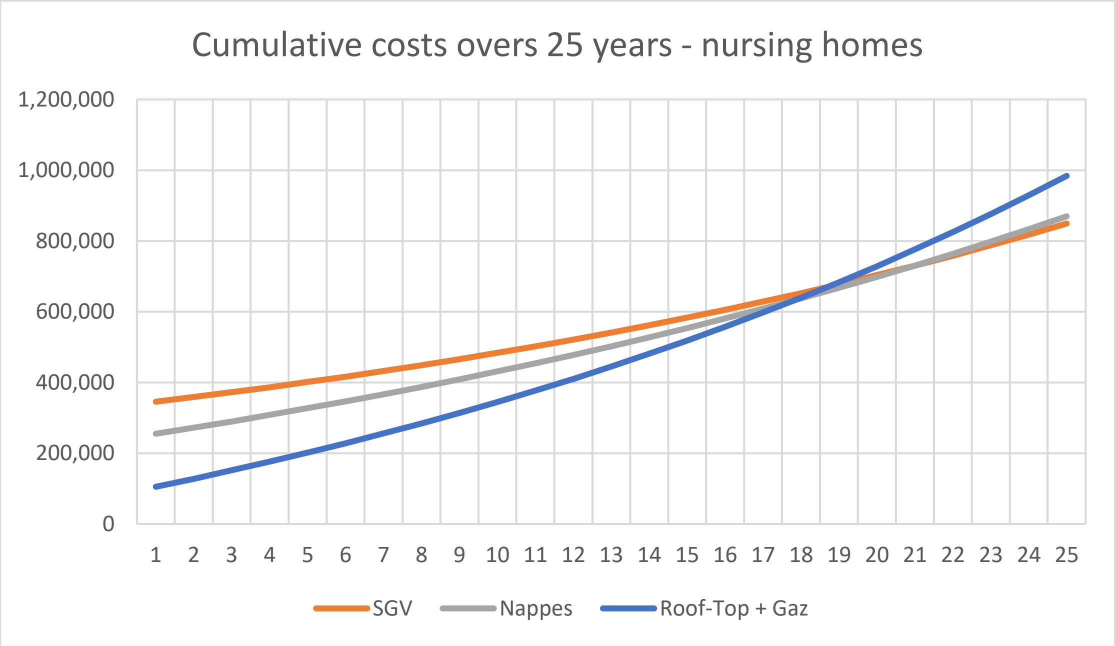

Figure 8 Cumulative costs for nursing houses

For the case of nursing homes, geothermal solutions become economically viable after 18 years, which represents a slightly longer period. However, it should be noted that this analysis does not take into account loans available at deeply discounted rates, which could make geothermal solutions even more cost-effective. Low-interest loans can significantly reduce upfront costs and shorten the payback period.

1-4-Levelized cost of energy

The average full cost of producing a megawatt hour of energy (LCOE) from geothermal energy is an essential indicator for assessing the profitability of this technology, because it takes into account all energy costs over the entire lifespan of the equipment. This indicator is also useful in the next part of the study to calculate energy costs in order to compare it with expected benefits. The LCOE was calculated for each case studied in order to obtain an accurate assessment of the production costs of geothermal energy.

The levelized cost of energy formula is:

$$LCOE = \frac{I_0 + \sum_1^n \frac{M_t + F_t}{(1+r)^t}}{\sum_1^n \frac{Q_t}{(1+r)^t}}$$

With :

• I0: Initial investment (€)

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• Mt and Ft: Maintenance cost (€) and operating cost (€) of year t respectively

o An expense equal to the price of the CAP will be added to this part during the 25th year.

• Qt: energy production of year t (MWh), this production is assumed to be constant

• r: discount rate – 4% which is the rate used for renewable energy projects

• n: lifespan of the installation at 50 years for SGV and water table installations

LCOE	Single family building	Collective building	Offices	Shopping center	Nursing home
BHE (€/MWh)	179	120	82	71	133
Aquifers (€/MWh)	-	111	87	65	118

Part II: role of renewable cooling in the mitigation of negative externalities: first results for the city of Paris

In the previous part, the technical and economic viability of geothermal energy as a solution for air conditioning and heating buildings was highlighted. As mentioned previously, geothermal cooling costs are directly related to overall costs, as drilling is a necessary and expensive step, regardless of the end use of geothermal energy. This section of the study now focuses on highlighting the quantitative and qualitative benefits of geothermal air conditioning, also looking at an example of the cost-benefit analysis of geothermal energy.

Geothermal air conditioning offers direct and obvious advantages over commonly used air conditioning solutions, such as packaged air conditioners, portable air conditioners, VRF systems, etc. These advantages include a reduction in energy consumption thanks to geocooling and/or the high performance of geothermal heat pumps, which are favored by the relatively constant temperatures in the basement and lower in summer compared to the temperature of the ground. outside air. In addition, this reduction in consumption naturally leads to a reduction in carbon emissions linked to geothermal air conditioning.

On the other hand, the majority of commercial air conditioning solutions are based on the refrigeration cycle, which is based on the principle of taking heat from the hot environment that we wish to air condition to reject it in another environment. In most conventional solutions, this medium is atmospheric air. On the other hand, for geothermal energy, the heat rejection takes place underground, thus offering an additional advantage which is to reduce the externalities linked to heat releases into the atmosphere. This makes it possible in particular to limit the effects of urban heat islands, which have negative consequences on the well-being of citizens by increasing temperatures in densely populated urban areas.

2-1-Urban heat island and heat waves

Urbanization has significant effects on urban climatic conditions, notably due to building density, land coverings such as streets, and anthropogenic sources of heat such as hot air emissions from automobiles, industries and air conditioning systems. These factors contribute to the urban heat island effect, characterized by higher temperatures in urban areas compared to surrounding areas.

Additionally, climate change worsens these heat island effects by exacerbating high temperatures. In fact, during heatwaves in Paris, temperatures in the city center are 8˚C higher than the surrounding areas. In addition, these heat wave phenomena are becoming more and more frequent in France with an increasing probability that they will occur once or twice a year

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by the end of the century. They are also likely to become longer and more intense, evolving from 5 to 8 days towards 10 days.[9]

For these reasons, it is essential to carefully examine the causes of urban heat islands and find solutions to reduce their impact. In this study, the focus is on the contribution of air conditioners to this phenomenon due to their heat rejection and electricity consumption. Additionally, the interest is in the potential role that geothermal energy can play in mitigating the effects of urban overheating.

A study carried out mainly by the Laboratory of Process Engineering for the Environment, Energy and Health and published in 2012 analyzed the effects of air conditioners on the outside air temperature in Paris[10]. In the study, several important criteria were considered such as weather data, land use types (buildings, parks, agriculture, water source, etc.), building data (such as the ratio between height buildings and the width of streets which is a very important factor for calculating solar gains), and the thermal and radiative properties of roads, walls and roofs.

Additionally, the study classified hot air discharge from air conditioners into three categories: evaporative cooling towers, dry air-cooling towers, and small dry air-cooling systems. With an indoor temperature set at 26˚C, four scenarios were studied and compared to a reference scenario without air conditioning. The first scenario represents the current air conditioning situation, while the second scenario assumes that all heat released is in the form of sensible heat. The third scenario assumes that the air conditioning installations are doubled and all the heat is released to the atmosphere as sensible heat. Finally, the last scenario assumes the same doubled installations, but with the hypothesis that all the heat rejection is carried out in the basement or in the Seine.

The results highlight that, in scenarios where heat release into the atmosphere is present due to air conditioners, outdoor temperatures are higher, both during the day and at night, compared to the scenario without air conditioning. Even if the origin of urban heat islands is mainly due to urban structures, the release of sensible heat plays a major role in the increase in outdoor temperature and the formation of these heat islands, with a contribution to the increase temperatures between +0.7˚C and +4˚C in the study. These results are consistent with other studies conducted in different localities such as Arizona in the United States[11], Berlin[12], and Hong Kong[13].

Furthermore, in commercial areas where air conditioning installations are widespread, they mainly contribute to the increase in outdoor temperatures which can reach up to 2.5°C and

[9] Lemonsu A, Viguié V, Daniel M, Masson V. Vulnerability to heat waves: Impact of urban expansion scenarios on urban heat island and heat stress in Paris (France). Urban Clim. 2015;14:586–605.
[10] Tremeac B, Bousquet P, Munck C de, Pigeon G, Masson V, Marchadier C, et al. Influence of air conditioning management on heat island in Paris air street temperatures. Appl Energy. 2012;95:102–10.
[11] Salamanca F, Georgescu M, Mahalov A, Moustaoui M, Wang M. Anthropogenic heating of the urban environment due to air conditioning. J Geophys Res Atmospheres. 2014;119:5949–65.
[12] Jin L, Schubert S, Salim MH, Schneider C. Impact of Air Conditioning Systems on the Outdoor Thermal Environment during Summer in Berlin, Germany. Int J Environ Res Public Health. 2020;17.
[13] Wang Y, Li Y, Di Sabatino S, Martilli A, Chan PW. Effects of anthropogenic heat due to air-conditioning systems on an extreme high temperature event in Hong Kong. Environ Res Lett. 2018;13.

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3°C. On the other hand, in neighborhoods where cooling network systems are widely used, the increase in temperature is less significant, which corresponds to a reduction in the effect of heat islands.

This effect caused by the cold networks is also highlighted in the results of scenario 4 where the heat is completely rejected into the ground or into the Seine. This scenario implies a reduction in the effects of heat islands, with a slight decrease in temperature compared to the reference scenario (from -0.5°C to -0.25°C) observed in areas where the installation of Air conditioners are common, especially in busy commercial areas. In this way, the impact of urban heat islands can be reduced and more comfortable conditions for the inhabitants of these areas[14] can be created.

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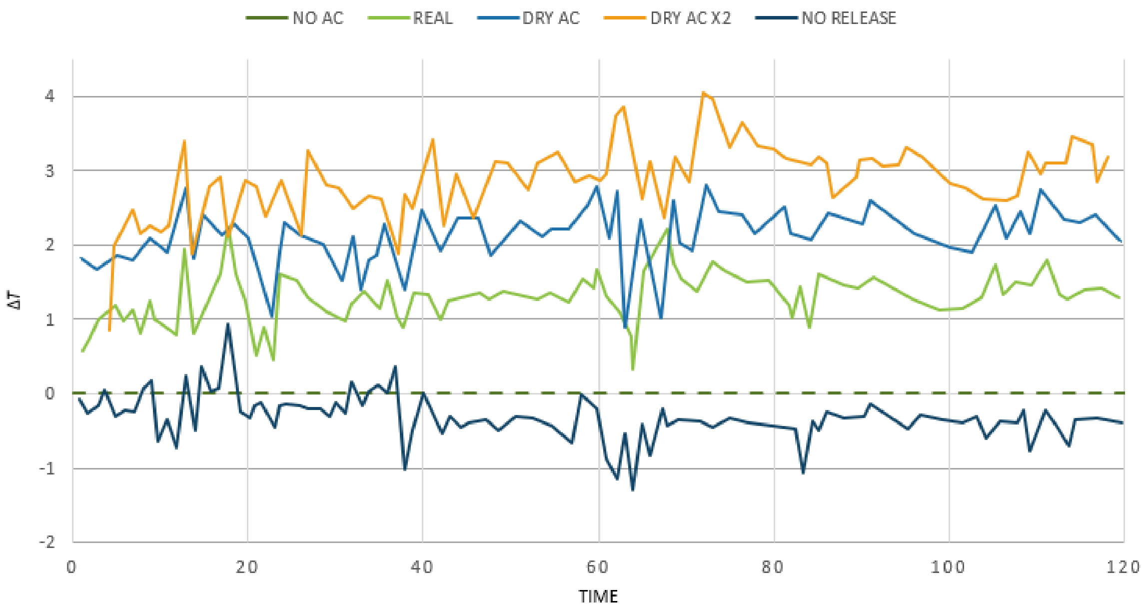

REAL	Current situation with individual dry air chillers, wet cooling towers and district cooling network
DRY AC	Scenario in which all the heat is rejected as sensible heat into the atmosphere
DRY AC X2	Air conditioning is doubled and heat is rejected into the atmosphere
NO RELEASE	Air conditioning is doubled and heat is rejected underground or into the river

Figure 9: External temperature variation according to each scenario in comparison to a scenario "without air conditioning" (reference ΔT=0)

[14] C. de Munck, G. Pigeon, F-E. Meunier, B. Tréméac, P., Bousquet, M. Merchat, P. Poeuf et C. Marchadier. Projet CLIM2 Climat urbain et climatisation. 2010.

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Thus, the use of dry cooling tower air conditioning contributes to increasing street temperatures, which creates an increased need for air conditioning to combat the enhanced heat island effect. Neighborhoods where dry cooling tower air conditioning is more widespread are particularly impacted by this effect[15]. However, another study carried out in 2020 in the city of Paris analyzed the effects of air conditioners on the outside temperature during heatwave periods and also noted a significant increase in electricity consumption[16]. According to this study, using a very optimistic assumption of a seasonal air conditioner energy efficiency ratio of 12 to 15, electricity consumption in the city would increase by 1.134 TWh due to air conditioning.

Furthermore, the study simulated ambitious solutions for mitigation and adaptation to heat waves, such as urban reconfiguration with more green spaces, strengthening of thermal regulations for buildings and changes in individual behavior. However, the results obtained revealed that these measures were not enough to eliminate the thermal stress caused in the absence of the use of air conditioners. Therefore, it is increasingly likely that air conditioning will be widely used in the future in Paris and large, densely populated cities.

All the results presented reinforce the idea of using geothermal energy as an air conditioning solution, where the rejection of heat into the ground or into water becomes a relevant and beneficial approach. By opting for these solutions, we manage to mitigate the effect of urban heat islands and maintain more moderate temperatures, thus providing a more comfortable environment for residents of the areas concerned. These environmental benefits, combined with energy savings and reduced long-term costs, make geothermal energy an attractive option for building air conditioning, both from a sustainability and economic efficiency perspective.

2-2-Health and well-being

Heatwaves cause varied health impacts, from fatigue and heat cramps to dehydration and heatstroke. These effects lead to functional alterations that make it difficult to perform tasks requiring physical effort or precision. Therefore, heat waves are generally associated with reduced productivity and increased mortality. Health costs linked to heatwaves represent a significant aspect of the overall economic impact, with significant consequences on production activities and the tourism sector. The economic impact of heatwaves remains a largely under-explored topic, even on an international scale.

During the three periods of heatwaves in 2022, Public Health France estimated an excess mortality of 2,816 deaths, or +16.7%, as well as more than 20,000 requests for care. People aged 75 and over are the population group hardest hit[17]. A study in China on temperature

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[15] Takane Y, Kikegawa Y, Hara M, Grimmond CSB. Urban warming and future air-conditioning use in an Asian megacity: importance of positive feedback. Npj Clim Atmospheric Sci. 2019;2:39

[16] Viguié et al. Early adaptation to heat waves and future reduction of air-conditioning energy use in Paris. Vincent Viguié Al 2020 Env Res Lett 15 075006.

[17] Santé publique France. Bilan canicule et santé : un été marqué par des phénomènes climatiques multiples et un impact sanitaire important [Internet]. 2022 Nov. Available from:

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impacts in urban areas also found a 4.5% increase in hospitalization rates for every 1°C increase above 29°C[18].

However, a study published by Santé Publique France and Aix-Marseille University estimated that the health consequences of heatwaves over the period from 2015 to 2020 represented an economic cost of 22 or 37 billion euros, depending on the methodology chosen. of which 6 billion are attributed to the restriction of activity and the loss of well-being[19]. According to a study conducted in Adelaide, Australia, a very pessimistic climate scenario (RCP8.5) will not only lead to an increase in the rate of hospitalizations linked to heat waves, but also an increase in the duration of hospitalization and associated costs[20].

Additionally, it is well known that high temperatures can have a significant impact on worker productivity. When the temperature rises above 24-26°C, productivity begins to slow down, and at 33-34°C, it drops significantly, up to 50%[21]. This phenomenon is known as "heat stress," which occurs when excessive heat exceeds the body's ability to tolerate ambient temperatures without suffering physiological alterations. The effects of heat stress on productivity are not limited to workers who spend a lot of time outdoors. Studies suggest that even office workers can be affected, and this may be due to a variety of factors, including difficulty sleeping during hot nights before work days and hot commutes to the workplace[22].

In order to improve health conditions during this critical period, it is essential to guarantee an adequate level of thermal comfort in buildings while reducing citizens' exposure to hot air emanating from air conditioners. High temperatures exacerbated by the effects of heat islands can lead to a reduction in the productivity and well-being of individuals when traveling or doing outdoor activities.

Renewable air conditioning solutions are needed to achieve these goals, including avoiding the use of atmospheric air as a heat sink.

In order to improve health conditions during this critical period, it is essential to guarantee an adequate level of thermal comfort in buildings while reducing citizens' exposure to hot air emanating from air conditioners. High temperatures exacerbated by the effects of heat islands

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https://www.santepubliquefrance.fr/presse/2022/bilan-canicule-et-sante-un-ete-marque-par-des-phenomenes-climatiques-multiples-et-un-impact-sanitaire-important.

[18] Chan EYY, Goggins WB, Yue JSK, Lee P. Hospital admissions as a function of temperature, other weather phenomena and pollution levels in an urban setting in China. Bull World Health Organ. 2013;91:576–84.

[19] Adélaïde L, Chanel O, Pascal M. Évaluation monétaire des effets sanitaires des canicules en France métropolitaine entre 2015 et 2020. Bull Epidémiol Hebd. 2021;(12):215-23. 2021; Available from: https://www.santepubliquefrance.fr/determinants-de-sante/climat/fortes-chaleurs-canicule/documents/article/evaluation-monetaire-des-effets-sanitaires-des-canicules-en-france-metropolitaine-entre-2015-et-2020

[20] Wondmagegn BY, Xiang J, Dear K, Williams S, Hansen A, Pisaniello D, et al. Increasing impacts of temperature on hospital admissions, length of stay, and related healthcare costs in the context of climate change in Adelaide, South Australia. Sci Total Environ. 2021;773:145656.

[21] Organisation internationale du Travail. Travailler sur une planète PLUS CHAUDE [Internet]. 2020. Available from: https://www.ilo.org/wcmsp5/groups/public/---dgreports/---dcomm/---publ/documents/publication/wcms_712010.pdf

[22] Zander K, Oppermann E, Kjellstrom T, Garnett S. Heat stress causes substantial labour productivity loss in Australia. Nat Clim Change. 2015;5:647–51.

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can lead to a reduction in the productivity and well-being of individuals when traveling or doing outdoor activities.

Renewable air conditioning solutions are needed to achieve these goals, including avoiding the use of atmospheric air as a heat sink. By opting for approaches such as geothermal energy, the effects of heat islands can be mitigated and the exposure of citizens to high temperatures ca be reduced, if not eliminated. Such approaches contribute to a healthier and more comfortable environment for everyone.

2-3-Costs of externalities

For this first Parisian case, the costs over 25 years of following externalities could be evaluated, with an actualization rate of 4%:

Costs spared over 25 years	
Mortality	234 062 381 €
Direct hospitalization costs	2 112 188 €
Time spent in hospital	10 955 153 €
Loss of productivity	732 994 753 €
Energy required for cooling purposes	3 646 924 885 €
Carbon emissions	95 669 012 €
Energy required for heating purposes	3 033 301 158 €
Total over 25 years	**7 756 019 530 €**

Figure 10: costs of externalities in a Parisian case (first estimation)

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Partie III _ Standardized methodology for several European cities

As regards the results in Paris as a first case study, it appeared necessary to simplify the methodology in order to extend it to other places in Europe. The partners decided:

- Not to take into account the subsidies. They namely depend on countries and time; and appear as costs for European citizen before they act as subsidies.
- To focus on the costs of fewer externalities due to the urban heat island (UHI) effect. The data needed for evaluating each externality are quite hard to find: it appears reasonable to evaluate only the main ones, that is the loss of productivity and the mortality.

That is the reason why the results on Paris were evaluated again, with a similar methodology as two other cities chose to be representative of European specificities: Roma and Bucharest. Paris has an oceanic climate, medium costs for energies, high costs for geothermal installations. Roma has a mediterranean climate, high costs for energies, medium costs for geothermal installation. Bucharest has a continental climate, low costs for energies, low costs for geothermal installation.

3-1-Description of the final methodology

For each city, the partners involved needed:

- To define the cooling needs at the city scale, and the way they are shared between several types of buildings. The results of the « Hotmaps » LIFE project were used as inputs when the information at the scale of the city were not available.
- To establish the cooling *and the heating* demand of each type of building in the city.
- To define a « classical solution for heating and cooling » as a reference case for each building and evaluate its costs. The reference case depends on the country such as on the type of building.
- To evaluate the costs of an efficient geothermal solution for each type of building, precising its performance (SCOP; SEER).

To evaluate the externalities (loss of productivity; mortality), the formulae given by the cited Austrian study[23] were used. This required:

- To find the number of deaths due to heat in the city, sometimes by evaluating it in regard of the total number in the country when the data could not be found.

[23] https://journals.sagepub.com/doi/10.1177/2399808320974689.

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- To compare the number of « hot days » in the city, defined as days with a maximal temperature over 30°C, with the number of hot days near the city. The assumption made is that the difference between these values is due to the urban heat island effect.
- To get the Gross Regional Product such as the population in the city.
- To establish a value for the wage[24].

Moreover, the following values at the European scale were used:

- Average productivity lost on hot days: 7%[25]
- Value of QALY: 5 000 000€, according to the "Recommended Value of a Statistical Life numbers for policy analysis" given by the OECD Library[26]
- Annual inflation of maintenance costs: 1%
- Annual inflation of energy costs: 4%
- Actualization rate: 4%

3-2-Results

The results are presented over 25 years. The choice was made to add the costs of the externalities which could be spared to the cost of the "reference case".

As a reminder, the partners of the project estimated that the 3 cities are quite representative of the main cases in Europe, since:

- Roma has a mediterranean climate, high costs for energies, medium costs for geothermal installation.
- Bucharest has a continental climate, low costs for energies, low costs for geothermal installation.
- Paris has an oceanic climate, medium costs for energies, high costs for geothermal installations.

[24] using a mean value over some years based on UNECE annual values https://w3.unece.org/SDG/en/Indicator?id=30
[25] https://www.semanticscholar.org/paper/Assessing-the-impacts-of-climate-change-for-V%C3%B6hringer-Vielle/ac7e20345459a46a8038161484b50eeff7f26916
[26] https://www.oecd-ilibrary.org/environment/mortality-risk-valuation-in-environment-health-and-transport-policies_9789264130807-en

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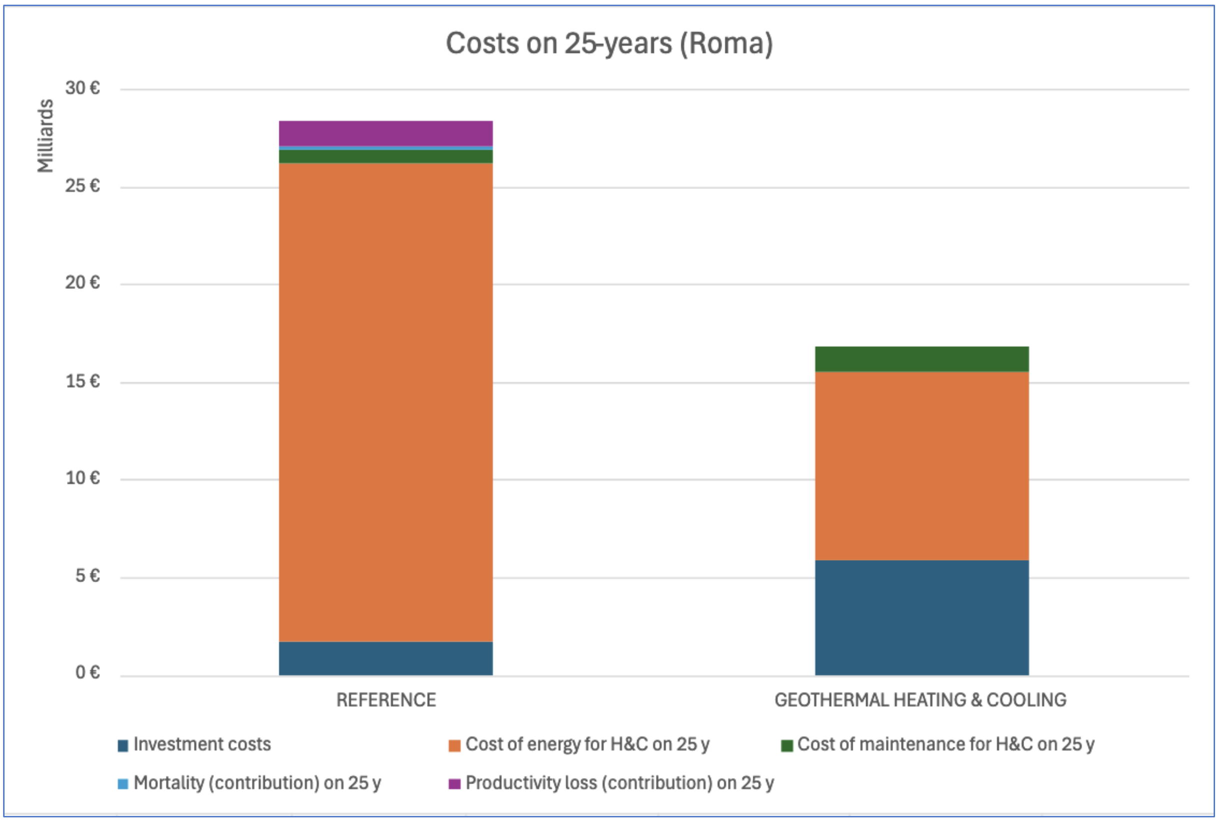

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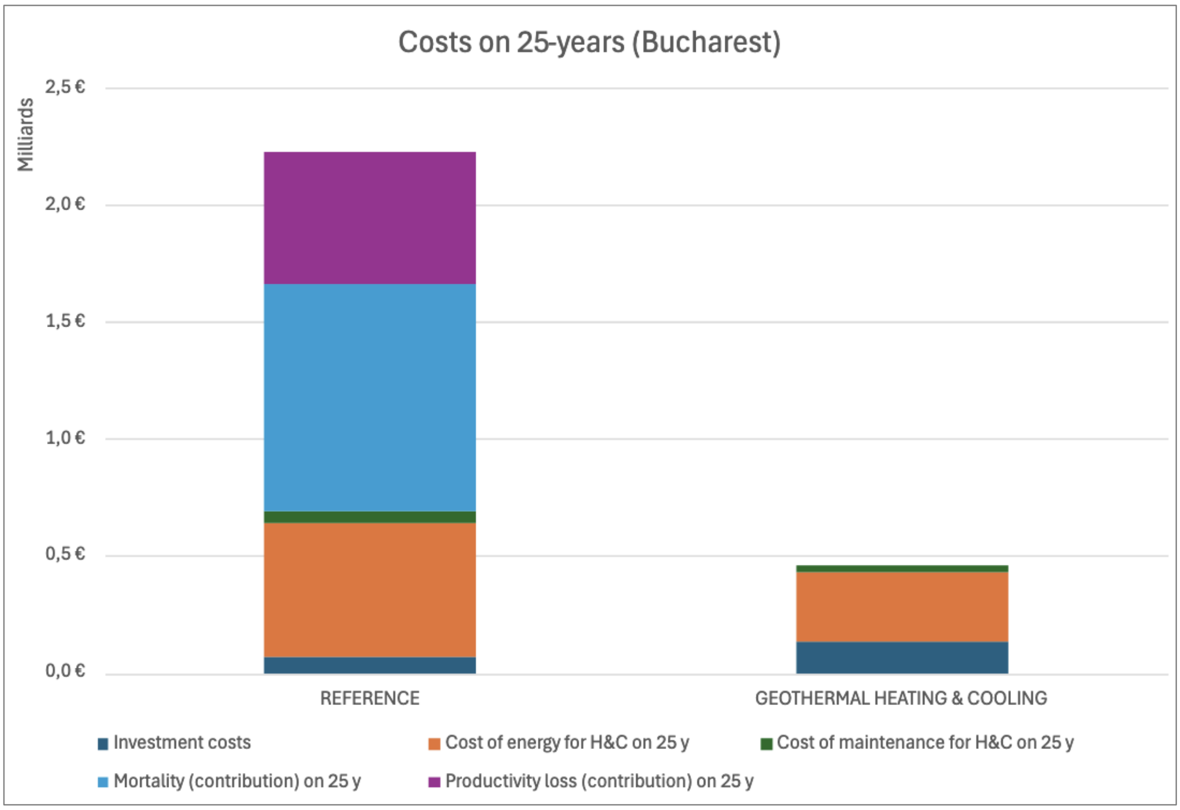

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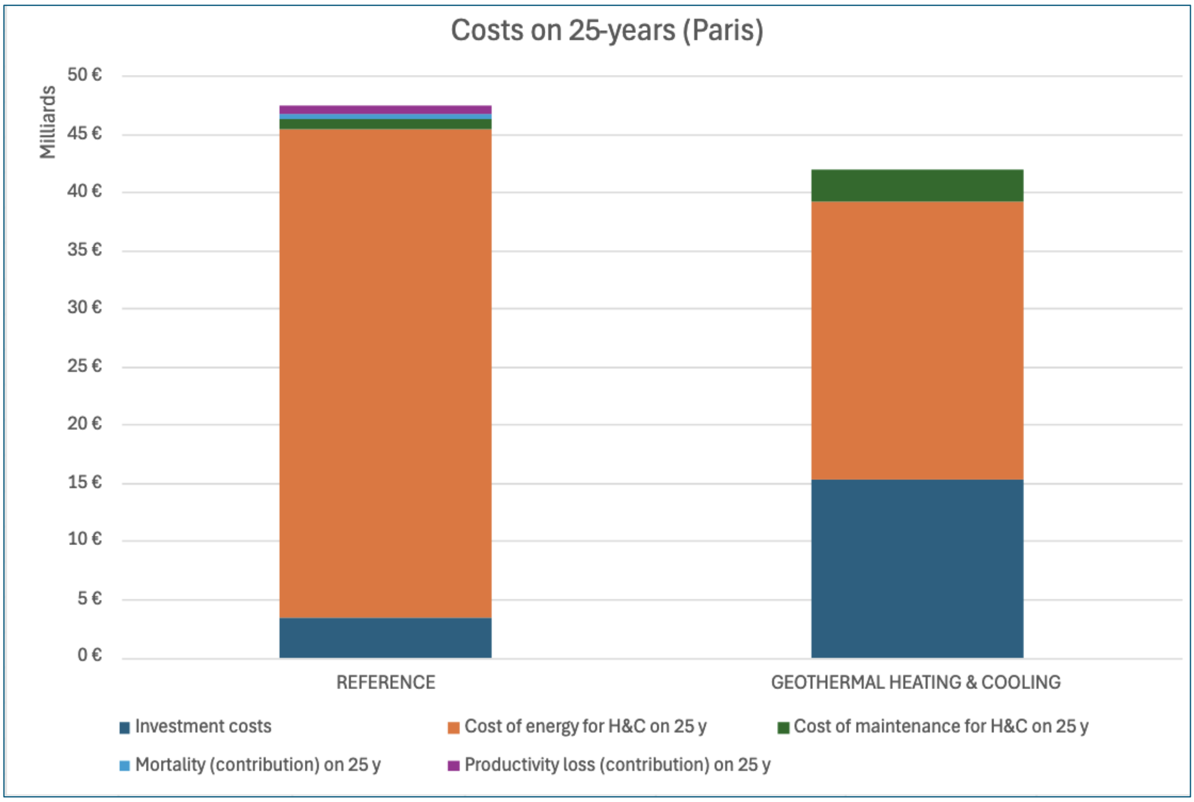

3-3-Analysis of the results

While the investment costs for (efficient) geothermal installations are each time significantly higher than for the reference solution, the total cost for the client (investment, energy, maintenance) over 25 years is each time lower. Moreover, the externalities over 25 years account for more than 1 billion euro in each of the three capitals. From a strict economical point of view, the public bodies have an interest to support and to contribute to the development of geothermal energy for heating and cooling.

As a reminder, some externalities were neglected or could not be evaluated, as the effect on the reinforcement of the electric grid; and some optimization like district heating and cooling were not considered at the city scale. That's why the effect should be even more important than presented here.

It is valuable to point out two key findings of the cited study of the Department of Energy in the USA[27]:

- (Key finding 1-C): *Because less grid infrastructure investment is required with the large-scale deployment of GHPs, they could reduce the cost of power for all grid consumers - even those who do not have the technology installed*

[27] https://info.ornl.gov/sites/publications/Files/Pub196793.pdf.

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- (Key finding 5): *Even though building heating is electrified with GHP deployment - increasing winter electricity use for homes and businesses that otherwise are heated with fossil fuels - the increase is more than offset by the electricity savings from the high-efficiency performance of GHPs for summer cooling and reduced thermal loads owing to weatherization in single-family homes, resulting in substantial net reductions in grid generation, capacity, and transmission*

This would need deeper expertise and study all over Europe, but it is plausible that same results should be found for all electric grids which would need reinforcement. In such a case, the operators for electricity transmission and distribution may have an interest in deploying geothermal cooling instead of more classical solution as air-source heat pumps.

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Part IV - Recommendations for stakeholders and regulatory building actors to address barriers

4.1 Recommendations to stakeholders, and actors involved in the regulation of buildings

Interested actors for renewable cooling technologies' includes relevant stakeholders for the uptake of renewable cooling in Europe. These stakeholders can be divided into[28]:

- **Regulators:** Policy bodies at local, regional and national level (municipal planners, energy managers in public authorities responsible for decisions in the energy field); Standards bodies.
- **Demand-side stakeholders:** individual building owners and landlords of houses and apartments; building managers of condominiums and multi-property structures, offices, shopping centres and health care institutions.
- **Supply-side stakeholders:** Specialists involved in the Geothermal HP, Solar thermal and other RES industry (HVAC engineers, installers, drillers, designers, architects); SMEs from the construction industry; Energy Service Companies (ESCOs)/ engineering companies, energy advisers, etc.); Associations in the European built sector.
- **Other stakeholders:** Scientific Community and Educational Institutions; public entities, chambers of commerce and industry, development agencies, energy agencies, centres of environmental expertise, professional associations, journalists & media; general public.

4.2 Tailored recommendations

4.2.1 Recommendation 1: integration of cooling in the energy system

Actors to target: regulators and supply-side stakeholders

System integration is key to be able to provide cooling solutions with lower costs. The two most important sectors for the integration of cooling systems are the heating sector and the electricity sector[29].

For the integration of cooling applications into the heating sector, major advantages arise from the possibility of combined heat and cold generation in Combined Cold, Heat and Power plants

[28] For a full list see Deliverable 5.1 'Catalogue of interested actors for renewable cooling technologies'.
[29] For a full analysis see Deliverable 2.1 'Report on cooling technologies, market, best practices and planning in Europe'.

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(CCHP) or heat pumps and the possibility to utilize 'waste' heat of cooling applications as a heat source for heat pumps.

The integration into the electricity sector enables the integration and utilization of renewable energy sources like wind and solar energy. In addition, cooling applications can offer flexibility for the electricity sector and open up the possibility of adapting generation to the changing conditions of volatile renewable energy sources by utilizing integrated thermal energy storages.

4.2.1.1 Integration of Cooling Systems into Heating Applications

Depending on the technology employed, there are multiple compelling reasons for integrating the generation of heat and cold. Many cooling applications, especially compression chillers, can be understood as a transfer of energy from a lower temperature level to a higher temperature level, resulting in a decrease in the temperature on the cold side and an increase in the temperature on the warm side. Therefore, it is obvious to not only utilize the cold but also make use of the heat.

However, there is a technology where the connection between heating and cooling is even more apparent. Thermally driven heat pumps utilize heat to generate cold and are considered the ideal choice when the heat source is renewable.

Another technology that combines all these factors and enables the local and temporal exchange of generated cold and heat is a 5th generation district heat and cold (5GDHC) grid. 5GDHC grids enable the exchange of energy between the actors involved in order to exploit synergies that occur when different purposes are considered collectively. The consumers in the district heating and cooling network can also act as producers by supplying energy to other participants. For example, the heat generated during refrigeration can be fed back into the heating network and used by other participants. This reduces the total energy consumption of the district by exploiting the simultaneity of the different demands. With the possibility of storing heat and cold seasonally through e.g. mine water, seasonal hot water storage, geothermal boreholes, this system also enables the integration of many renewable energy sources such as waste heat or solar energy.

Best Practice Example: Minewater 2.0 Heerlen
Minewater 1.0 is the term used for the initial mine water system at Heerlen, developed in the period 2003 - 2008. It started as a straightforward pilot system to investigate how the mine water of the abandoned coal mines of Oranje Nassau could be used as a geothermal source for the sustainable low-exergy heating and cooling of buildings. For the extraction of hot water with a temperature of about 28 °C, two hot wells in the northern part of Heerlen with a depth of 700 meters below surface and two cold wells in the southern part of Heerlen with a depth of 250 meters for the extraction of cold mine water with a temperature of about 16 °C and one intermediate injection well with a depth of 350-400 meters for the collective injections of used mine water, were used. A simple change-over system only able to supply heat in winter and cold in summer. In 2012/13 the Minewater project was upgraded from a straightforward pilot system to a full-scale hybrid sustainable energy structure called Minewater 2.0. At that time, a totally new concept which has the following landmarks:

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• Energy exchange instead of only energy supply: cluster grids were deployed to exchange heat and cold between buildings inside a cluster and between the cluster grids through the central mine water grid. The grid became a bidirectional grid able to supply heat and cold at any time. Each user becomes a prosumer, not only extracting heat or cold but also discharging cold and heat in return that can be used by other users in the grid, with an opposite demand.
• Energy storage: sse of the minewater reservoir as a seasonal storage, actively regenerated by the surplus of heat and cold in the grid during the year in addition to the geothermal regeneration to increase the renewable capacity.
• Able to implement multiple sources like waste heat from industry, data-centres or supermarkets.
• Expansion of the hydraulic and thermal capacity of the mine water reservoir and grid: enlargement of the mine water grid by improving well pumps, implementing pressure boosting systems for fully automatic control and transforming them into bidirectional wells and reuse of the existing mine water return pipe for additional supply and disposal of cold mine water.

Since the concept is successful the owner and the public authorities decided in 2023 to invest 300 Mio. Euro into the expansion, the further development of the facility and the transfer of the concept to other communities.

Key learnings
What made the project successful:
• Strong support from the authorities
• Providing clusters with cluster grids to overcome technical and economic barriers
• Market that understands the system/concept of prosumers
• Openness for new pricing models
• Continuous steering in all phases from the (owner and) operator as ‘master-of-concept’
• Importance of communicating and collaborating between operator and engineering consultants to meet the special technical requirements
• Creating blueprints for the design and execution of the units/system elements (Building blocks)
• Central operation system, which communicates via internet, supervised by the operations
• Cold supply improves the business case. Extra product and fee to cover investment costs and regeneration source to improve the systems efficiency.

4.2.1.2 Integration of Cooling Systems into the Electricity Sector

Electrification will be a key driver of the energy transition in Europe, due to the availability of renewable energy sources such as solar energy, wind energy and geothermal energy and their efficient conversion into electricity. However, for the grid it is crucial to maintain a secure electricity supply and continuously balance generation and demand. Traditionally, this has been achieved through demand-oriented trading on the electricity exchange. In times of high demands, the price for electricity is rising and additional power plants with higher production costs can sell their generated electricity.

However, as renewable energy sources are not controllable in the same way, the trading of energy from RES brings new dynamics to the electricity exchange and may lead to a higher volatility in the prices. Therefore, it could become increasingly important and economically

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beneficial to develop solutions to align electricity demands with the generation of electricity from renewable energy sources rather than vice versa.

Best practice example: EUREF "Energiewerkstatt" by GASAG Solution Plus

The EUREF Campus is home to several technology companies, offices and research institutions, which have a high demand for cooling both office spaces and server rooms. The EUREF "Energiewerkstatt" by GASAG Solution Plus supplies 25 buildings with heating and cooling on the campus with a total area of 165,000 m².

The EUREF Campus' energy centre consists of a variety of different energy plants, including a biomethane powered combined heat and power plant (CHP) with 400 kW electrical output and 431 kW thermal output, two low-temperature gas boilers with 2.1 MW thermal output each, high-efficiency pumps and a self-generated electricity combined heat and power plant with 50 kW electrical output and 100 kW thermal output.

The cooling is provided by two 1 MW electricity-driven compression refrigeration machines and distributed via a district cooling network. Furthermore, two 22 m³ buffer tanks are installed in the EUREF Campus' energy centre, which can be used for either heat or cold storage, depending on the planned operation. The cooling supply is required at the EUREF Campus research site all year round for both office conditioning and server rooms. At low ambient temperatures, it is possible to use free cooling, which saves on the compression process and increases the efficiency of cooling generation. The electricity generated in the combined heat and power plant can be used either directly in the buildings or to generate heat or cold in the own compression refrigeration machines.

A stakeholder driven project

The GASAG Solution Plus is the driving force behind the planning of the energy system on the EUREF-Campus. They are both the planner and operator of the facilities, responsible for developing the original concept and operating strategy. They also handle maintenance and repairs. The conceptual energy system was developed using their own innovative methods and conventional planning tools.

The intelligent control system for the energy centre was developed by another member of the GASAG Group Geo-En Energy Technologies GmbH as part of another research project. The development and implementation of the measurement, control and regulation system had to be closely integrated in the design process to ensure the planned operation. The hydraulic implementation was commissioned to external service providers but was also developed in close collaboration. With a contracting agreement, the companies on the EUREF campus purchase heat and cold for their office spaces or server rooms from the GASAG Solution Group for a monthly base price, plus a variable price for the energy supplied.

Furthermore, a communication channel to the electricity market had to be established. Participation in the electricity exchange can either take place directly, if the necessary IT infrastructure and exchange trader qualifications are available, or indirectly via the electricity providers or specialized brokers. The GASAG AG is a trading participant on the EEX electricity exchange and therefore has direct access to the spot market.

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4.2.1.3 Conclusions and recommendations

This subchapter demonstrates the benefits of integrating cooling applications into the heating and the electricity sector and the importance of incorporating cold storages in highly renewable energy systems.

For integrating cooling applications into heating systems, the best practice example "Minewater 2.0" illustrated the potential of integrating cooling systems into heating applications and how they profit from each other. For Minewater 2.0, it was necessary to achieve a certain number of heating network connections to be economically viable. Therefore, the support from local and public authorities was of particular importance as they had to promote the system until it had reached the required dimensions. Nevertheless, it needs to be mentioned that the benefits of integrating cooling and heating applications can also be found at smaller scales.

The best practice example of the EUREF "Energiewerkstatt" by GASAG Solution Plus demonstrates the benefits of integration cooling systems into the electricity sector. As the share of renewable energy in the electricity mix increases, electricity prices become more volatile and decrease in times of high availability of renewable energy sources. Participation of cooling system operators in the electricity market and the utilization of their flexibility promises to increase economic viability and further promote the use of renewable energy sources.

However, the economic viability of integrated systems like the EUREF "Energiewerkstatt" does not only depend on the electricity prices from the electricity exchange but also on the prevailing political and regulatory framework. To effectively integrate renewable energy and utilize flexibility on a wider scale, there is a need for additional economic incentives.

Currently, the alignment with electricity market prices has not reached typical end consumers due to government-mandated, rigid, and regulated components of the electricity price. These components, such as taxes, grid fees, and levies, account for more than 75% of the electricity price for consumers in Germany[30]. Consequently, the deployment of energy storage and demand management lacks sufficient incentives, as consumers still face high levies even during periods of low or negative wholesale prices, although they could help to relieve and balance the electricity grid. Therefore, there is significant potential to expand incentives and enable a more flexible electricity price orientation from the consumer's perspective. When considering grid-friendly operation of heating and cooling systems, it should be examined whether grid fees could be made more flexible to incentivize such operation or how additional incentives could be developed for this purpose. In addition, both case studies have shown that consistent project management across all phases from planning to operation appears to be a promising approach for the success of a project.

Furthermore, integrated cooling systems offer several general points of support for their widespread adoption. Firstly, there is a need for a market that fully understands the system and the necessity for new pricing models. Additionally, it is crucial to disseminate the knowledge held by a few companies to the wider public through the establishment of norms,

[30] Sensfuß F, Lux B, Bernath C, Kiefer CP, Pfluger B, Kleinschmitt C et al. Langfristszenarien für die Transformation des Energiesystems in Deutschland 3. Kurzbericht: 3 Hauptszenarien. Karlsruhe: Fraunhofer ISI, Karlsruhe; 2021.

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guidelines, educational initiatives, and performance indicators. Moreover, it is worth exploring the potential recognition of the cold generated by integrated systems as CO2-neutral. These factors collectively contribute to the compelling case for the expansion of integrated cooling systems.

4.2.2 Recommendation 2: taxation and financing framework

Actors to target: regulators, supply-side stakeholders, other stakeholders

Taxes account for a significant share of the final prices consumers pay for energy around the EU and can have a strong impact on consumption and investment patterns, the type of energy consumed and their use. This is reflected by the different rates of energy taxation in different EU countries, with important variations between households and industrial use, between different energy sources and with rates that bear little relation to the energy content or externalities, such as CO2 emissions or air pollution. Taxation policy is also an important instrument for governments to ensure the achievement of the energy union objectives, and in particular to facilitate the clean energy transition. A different taxation of electricity and gas is seen as a driver, especially when gas is less taxed. A lower VAT rate for geothermal DHC networks is also seen as a supportive element.

4.2.2.1 Taxation of energy products

Under current Energy Taxation Directive provisions, geothermal heat pump technologies are more expensive compared to fossil gas, as the latter still benefit from low minimum rates and numerous exemptions. EU legislators recently agreed to introduce a carbon price on buildings and road transport fuels31. The new carbon price will apply to petrol, diesel and heating fuels such as natural gas.

As regards the national level, an important example is given by Finland, by letter of 6 August 2021, following the procedure laid down in Article 19 of Directive 2003/96/EC, requesting authorisation to apply a reduced rate of taxation to electricity supplied to heat pumps and electric boilers that generate heat for the district heating network, to heat pumps with a nominal thermal output of at least 0,5 MW not connected to the district heating network, and to recirculating water pumps in geothermal heating plants. On 17 June 2022, the Commission authorised this legislation for the period from 1 January 2022 until 31 December 2027[32]. The Finnish example should be considered as a best practice in terms of energy taxation.

To push for cooling solutions based on renewable energy sources, it is necessary to further promote and not limit in time the applicability of legislative measures such as the Finnish ones. A reduced rate of taxation on electricity supplied to renewable cooling solutions must be

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[31] The European Commission issued in 2021 its proposal to recast the Council Directive 2003/96/EC for restructuring the Community framework for the taxation of energy products and electricity ("Energy Taxation Directive" or "ETD"), which is still under negotiation in the EU Parliament and Council.

[32] Council implementing decision (EU) 2022/1004 of 17 June 2022 authorising Finland to apply a reduced rate of taxation to electricity supplied to certain heat pumps, electric boilers and recirculating water pumps, in accordance with Article 19 of Directive 2003/96/EC.

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promoted. Similar solutions should be taken in other Member States to create a levelled playing field for geothermal DHC networks.

4.2.2.2 The importance of energy price regulation

Energy price regulation is another factor which can boost geoHC networks. For example, in Denmark, a new political agreement on price regulation for geothermal energy was adopted in December 2021[33].

Pricing now can take place through a contract between the district heating and cooling company and the geothermal operator, which places a cap on the costs consumers will pay for the geothermal heat and cold. The Danish Supply Authority, as an independent authority, must approve the exemption and check that the conditions are met.

At the same time, it is ensured that consumers do not have to bear the risk associated with the kilometre-deep drilling in the underground.

4.2.2.3 Setting the right legislative framework for public-private partnerships

Public-Private Partnerships (PPPs) describe a form of cooperation between the public authorities and economic operators. The primary aims of this cooperation are to fund, construct, renovate or operate an infrastructure or the provision of a service. PPPs are characterised by:

- the duration of the relationship between the partners;
- the method of funding the project;
- the role of the partners in the definition of objectives, design, completion, implementation, and funding;
- the distribution of risks.

At EU level, three directives dealing with PPPs have been transposed into national law by EU countries:

- Directive 2014/24/EU on public procurement;
- Directive 2014/25/EU on procurement by entities operating in the water, energy, transport and postal services sectors;
- Directive 2014/23/EU on the award of concession contracts.

Indeed, another way national legislation can favour the development of geothermal cooling networks is through the creation of a legal framework to support public-private partnerships[34].

Technical solutions have made significant advancements and have been successfully demonstrated also for efficient solar cooling systems[35]. Despite these achievements,

[33] See https://danskfjernvarme.dk/aktuelt/nyheder/2022/politisk-aftale-giver-haab-for-at-vi-nu-kan-udnytte-potentialet-for-geotermi.
[34] See subchapter 4.2.4 for a more detailed analysis on PPP.
[35] Jakob et. al, 2021; Beccali et. al, 2022; Neyer and Jakob, 2022; Jakob and Calderoni, 2023; Jakob et. al, 2023; Gurtner et. al, 2024; Jakob et. al, 2024.

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substantial non-technical barriers and risks frequently limit a widespread adoption of solar cooling systems[36].

A primary obstacle is the substantial upfront capital expenditure (CAPEX) required for solar cooling systems compared to conventional (mostly fossil fuel) alternatives (with high OPEX), which renders financing critical or unfeasible in certain instances. Also, potential clients' perception of risk due to complexity or unfamiliarity with solar cooling technologies further hinders the adoption process. These and other non-technical challenges underscore the importance of developing client- and service-oriented solutions to overcome financial and risk perception barriers. Addressing these challenges is crucial for expediting the adoption and implementation of solar cooling technologies.

Quite some hopes are placed on Third Party Financing (TPF) and energy service business models (BM), also known as ESCo models, to overcome these barriers. ESCo's shall serve as a 'delivery mechanism' for solar cooling solutions on the way to higher implementation rates. Developing suitable financing options and BMs necessitates collaborative discussions and joint efforts involving solar cooling engineers, researchers, investor and financing communities, potential clients and off course policy support.

4.2.3 Recommendation 3: private financing

Actors to target: supply-side stakeholders, demand-side stakeholders

The deployment of geothermal cooling technologies at scale is dependent on the availability of private financing.

4.2.3.1 Actors & role

There are several categories of actors that provide private financing to geothermal cooling projects, each with their own specific characteristics. However, private investors are looking to balance the risk and profitability of their investments, usually reflected in a metric such as the cost of capital. Different types of investors will have a different tolerance to risk: for instance, a large financial institution with a diversified project portfolio may be more willing to invest in a riskier geothermal project than a small investor that would entirely rely on said project.

Category of private investor	Type of geothermal projects supported	Type of financing provided
Local banks	Geothermal heat pumps (individual, large buildings, business…), district heating…	Loans

[36] https://www.iea-shc.org/Data/Sites/1/publications/IEA-SHC-Task65-DD2.pdf.

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Private equity	Geothermal developers, manufacturers, large projects (district heating and cooling, electricity)	Equity financing
Pension funds	All	Any, through private financial institutions such as banks or PE
Investment banks	Refinancing, manufacturers, utilities, large scale project financing	Loans, equity, complex financial products
Households	Geothermal heat pumps, district heating and cooling	Private investment, heat bills payment
SMEs	Geothermal heat pumps, district heating and cooling, small electricity projects	Private investment (equity), corporate PPA
Utilities	All (typically larger projects)	Private investments, project finance (typically structured by involving other investors)
Citizens/energy communities	All, usually projects within the community	Crowdfunding (loans, grant, equity…)

4.2.3.2 Instruments

Various instruments allow geothermal project developers to gather the necessary capital for their geothermal cooling project. Instruments can be deployed at various scale: there are for instance significant differences in the loan provided to a household for installing a geothermal heat pump in their home by a local bank, and the loan provided by an investment bank to a utility for the financing of several large-scale geothermal projects in export markets. The financial instruments usually provided by private financial actors to geothermal projects include:

- Loans: the provision of a sum of money that must be paid back to the investors (at an interest). Loans are an attractive option for developers in the current financial conditions of low interest rates. However, they require a robust derisking framework and a degree of maturity in the geothermal energy market as investors want to minimise their risks.
- Equity: in providing equity, private investors become directly involved in the projects, and do not receive a return if the project is not profitable enough. As a riskier form of financing, it is usually provided either directly by developers, or at

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later stages of the project where the geothermal risk has been mitigated to a large extent.

- Corporate Power Purchase Agreements (PPAs) are an emerging financing instrument for geothermal project developers. By securing the demand for the geothermal energy produced, developers ensure their income, which in turns reduces the financial risk profile of the project. Corporate PPAs are emerging rapidly as the evolution of public operational support framework is exposing developers to more financial risks.

There is no single private financial instrument that is inherently better for geothermal cooling technologies. Moreover, beyond direct financing, some financial instruments can be directly relevant to the market uptake of geothermal energy projects. For instance, securities backed on the provision of geothermal energy, harmonized within the framework of the EU sustainable finance taxonomy, can allow to direct new financing to the geothermal sector. However, such complex financial products are only emerging in the renewable sectors and need a harmonized set of standards to prevent greenwashing.

4.2.3.3 Corporate sourcing of geothermal energy

Corporate sourcing of energy is used by corporations or public authorities to secure their supply of renewable energy. More conventionally they have been used – notably beyond the EU in markets such as the US – by utilities to source power capacity, for instance from renewables. The benefit of corporate sourcing is to provide certainty for both parties: the energy producer has a higher certainty on income with a stable customer at a predetermined price. The consumer benefits from certainty on price in the long term. Corporate sourcing of energy may take various contractual forms. It may correspond to Power Purchasing Agreements (PPA, where an agreement is made for the long-term sale of energy by two parties), to a joint venture or event to a corporation investing in its own geothermal project.

4.2.4 Recommendation 4: the right business model for each situation

Actors to target: supply-side stakeholders, demand-side stakeholders, legislators

Different business models are available for cities, industries and energy consumers.

- **Cities**
  The two traditional business models for DHC networks in cities are are:
  a) The case of a DHC company decarbonising its heat supply in close cooperation with Energy Service Companies (ESCOs). Here, the main marketing strategy would be to combine renewable heat supply (possibly with the use of labels or certificates) and energy-saving services to widen the scope of activity and reduce energy consumption.
  b) The second case concerns a geoHC project developer (public or private) aiming at proposing a new DHC system with geothermal heat & cold supply. The objective would be to convince heat users of the value of renewable energy sources, which are local, stable and competitive.

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Before the drilling of the first well, a contract has to be negotiated to sell the heat and cold to a minimum number of customers to make the project economically viable. This step is of paramount importance; many projects cannot find any financial support if this type of heat and cold purchase agreement is not provided to the bank before beginning the negotiation and after covering the geothermal resource risk (see the previous subchapter).

There are two different cases:

- If the district heating and cooling network already exists and some technical modifications are needed in the network or the stations and substations, the client is identified (public or private or a mix), and a pre-contract has to be negotiated. It aims at signing a minimum agreement to purchase a certain amount of heat per year during a sufficiently long period, usually between 15 and 30, to secure the reimbursement of the bank loan, depending on the laws in force in the country.
- If the district heating and cooling network is to be built, the same type of agreement has to be signed and negotiated with guarantees of quantity, price and duration of the heat sales contract. Separate contracts will be required if there are several clients.

  Traditionally, geothermal HC projects have included the following stakeholders:
  - A state developer, sometimes an incumbent operator partially or fully publicly owned by the State.
  - Private project developers and operators, established with the liberalisation of the energy market.
  - Local authority (such as a municipality - common in France)/ local public utility (common in Germany).

Usually, geothermal projects have seen two major business models:

a) Public ownership projects

   Public projects driven by municipal authorities (France) or local utilities (Germany), The local public entity develops the projects during all phases: resource exploration, drilling, plant installation and operation of the geoHC network. It contracts private companies to supply services, supply of equipment and works. It operates the network and fixes the price. This model is beneficial to local projects supplying heating and cooling to building blocks or residential networks. This BM is very common in Germany and is used sometimes in France.

   An example is the Freiham's (Munich, Germany) district heating and cooling plant[37]. Stadtwerke München (SWM), Munich's municipal utility company, has been heating and cooling the Freiham district and neighbouring districts in the west of Munich since Autumn 2016.

b) Public-private partnership (PPP) to develop and operate the plant and the system.

   This private-public partnership (PPP) includes a private utility or private company in addition to the local public authority or utility.

[37] https://www.geothermie.de/bibliothek/lexikon-der-geothermie/m/muenchen-freiham-geothermieanlage.

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It has been the traditional business model of geothermal district heating systems in France since the 80s. Here, the municipality is the one taking the risk and having the responsibility of the project development. However, it contracts a private entity to develop the project. The French financial risk mitigation scheme allows the municipality to cover this risk. It takes here typically 4 years to develop such a project. This standard PPP model is used in the geothermal project schemas from ENGIE and Dalkia in France.

The municipality associated with the private developer contracts private companies to supply services, equipment, and work during the project development phase. The city delegates then to the private operators the project management and operation for some decades. The heat price is controlled by both parties

The profitability can be increased by formally constructing partnerships between public and private partners to spread out the risk to multiple partners and by involving public partners the demands regarding payback time and return on investment tend to be more accommodative. Regarding the responsibility of the different partners, the model below gives a brief overview.

An example of the increased use of alternative business models is the Hungarian case, where the change in the use of business models in the GeoDHC market is a clear example. Today, a third of the systems are operated in a PPPs, the majority being managed by local public authorities, but more than half of GeoDHC's ongoing projects are developed by a private operator. One aim is to establish PPP with local municipalities. One key piece of information is to communicate about the project, especially the heat price. As an example, in France, all DHC systems are mapped and reported online.

- **Industries**

  The corporate source option briefly described in the subchapter above can provide business models for industries, in particular with heat and/or cool purchase agreements.

Heat and/or cool purchase agreements
A heating and/or cooling purchase agreement is concluded directly between an energy producer and a consumer company. In recent years, this form of purchase agreement, historically reserved for very large consumers of grey electricity, has been developed more widely around the world for all types of consumers, especially those wishing to be supplied directly with renewable electricity. The company commits a renewable energy developer or energy supplier to purchase a given volume of electricity at a predefined price (fixed, indexed, bounded, etc.) for a period of 3 to 20 years. In return, it receives the energy produced as well as the associated guarantees of origin, directly participating in the creation of new renewable energy assets or in the continuity of operation of assets that are no longer under the purchase obligation. In the case of green heat or cooling, the production assets (biomass boiler, biomass cogeneration, waste treatment plant, geothermal system, solar thermal…) are necessarily located near the site or on the site. They are connected via a dedicated network.

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Corporate sourcing of geothermal energy is a promising avenue for the geothermal industry. **For the cooling sector, this could specifically apply to data centres**. Suitable policy and regulatory frameworks are needed to enable the development of this practice. The framework for corporate sourcing of renewable energy needs to be flexible enough to allow the various type of schemes and business models that can be implemented.

- **Other energy consumers: communities and individuals**

Other energy consumers to consider are individuals or communities of people. Here the focus will be on the main business model that can serve a group of people: the energy community.

Energy communities

Energy communities enable collective and citizen-driven energy actions to support energy project development and operation.

These energy communities contribute to increasing public acceptance of renewable energy projects and making it easier to attract private investments in local energy assets. By empowering citizens to drive their energy supply locally, they also benefit from better energy efficiency, lower bills, and security of energy supply. Energy communities also allow local communities from surrounding cities to join forces and invest in common energy projects. Energy communities act as a single entity, they can then access to electricity, heat and cold markets on a level playing field with other energy market actors. Under EU energy legislation, energy communities are defined and regulated. They can take different form of legal entity, including an association, a cooperative, a partnership, a non-profit organisation or a limited liability company.

In geoHC projects, there are two main barriers for renewable energy communities of individual consumers:

1) the capital investment is intensive for large-scale projects, typically €1Mio/MWth;

2) the risk component during the exploration and drilling phases typically adverts such communities.

This is why the geothermal sector has not seen the development of such renewable energy communities for project development so far. But an example can be given of such schemes with an alternative model: geothermal 5th generation of district heating and cooling (Geo5GDHC).

Geo5GDHC connects distributed individual prosumers with heat pumps to a heat / cold network that distributes energy supplied by small-scale geothermal installations. The grid allows for combined heating and passive cooling, capable of shifting thermal loads by seasonal energy underground storage. Currently, there

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are twelve commercial Geo5GDHC grids in Denmark using different energy sources and models for ownership and operation. Some more exist in the rest of Europe.

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ANNEX I: Description of cooling needs and externalities

The assumptions made fort Part III are detailed in this annex.

Roma

Cooling needs: 1930 GWh/y

- 10% for single-family houses
- 53% for collective (residential) buildings
- 23% for offices
- 12% for shopping malls
- 2% for health facilities

HD is the average number of hot days reduced per year	12
Gross Regional Product per capita	37 180 €
Pop is the population of the city	2 813 000
w is the wage	59%
p is the average productivity loss on hot days	7%

AF is the attributable fraction of deaths due to heat	0,283
TD is the total deaths over the time period	92
Y is the total number of years in the time period	1
HD,avg is the current average annual number of hot days	73
HD,red is the reduced number of hot days	12
Value of QALY (€)	5 000 000 €

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Bucharest

Cooling needs: 52,5 GWh/y

- 30% for residential, considered as single-family houses
- 33% for offices
- 37% for shopping malls

HD is the average number of hot days reduced per year	10
Gross Regional Product per capita	22 000 €
Pop is the population of the city	**1 716 961**
w is the wage	**45%**
p is the average productivity loss on hot days	7%

AF is the attributable fraction of deaths due to heat	1
TD is the total deaths over the time period	75
Y is the total number of years in the time period	1
HD,avg is the current average annual number of hot days	63
HD,red is the reduced number of hot days	10
Value of QALY (€)	**5 000 000 €**

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Paris

Cooling needs: 3044 GWh/y

- 2% for single-family houses
- 6% for collective (residential) buildings
- 48% for offices
- 28% for shopping malls
- 16% for health facilities

HD is the average number of hot days reduced per year	6
Gross Regional Product per capita	57 600 €
Pop is the population of the city	2 145 906
w is the wage	59%
p is the average productivity loss on hot days	7%

AF is the attributable fraction of deaths due to heat	0,283
TD is the total deaths over the time period	92
Y is the total number of years in the time period	1
HD,avg is the current average annual number of hot days	17
HD,red is the reduced number of hot days	6
Value of QALY (€)	5 000 000 €

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ANNEX II: Description of buildings and costs

For each building, the first column refers to the reference solution and the second one to the efficient geothermal operation used for both heating and cooling.

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	ITALY - ROMA									
	Individual house		Collective (residential) building		Office		Commercial center		Health facility	
Heating needs (MWh/y)	11,468	11,468	83,9	83,9	154,186	154,186	416,88	416,88	180	180
Cooling needs (MWh/y)	3,4	3,4	40,7	40,7	151,2	151,2	439,8	439,8	371,2	371,2
Process needs (MWh/y)							1675,52	1675,52	80	80
Efficacity (heating)	0,98	4,5	0,98	4,5	3,28	4,5	3,28	4,5	3,27	4,5
Efficacity (active cooling)	2,8	6	2,8	6	2,86	6	2,86	6	2,97	6
Efficacity (passive cooling)		30		30		30		30		30
Ratio of active cooling	100%	50%	100 %	50 %	100%	70%	100%	70%	100 %	70%

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Investment cost (€)	8 830,00 €	30 000,00 €	35 205,00 €	130 000,00 €	98 318,00 €	280 000,00 €	161 568,00 €	630 000,00 €	83 500,00 €	405 000,00 €
Maintenance cost (€/y)	150,00 €	150,00 €	560,00 €	1 250,00 €	750,00 €	2 250,00 €	1 500,00 €	3 700,00 €	750,00 €	2 650,00 €

Electricity cost : fix (€/y)										
Electricity cost : variable (€/MWh)	250,00 €	250,00 €	250,00 €	250,00 €	220,00 €	220,00 €	220,00 €	220,00 €	220,00 €	220,00 €
Other energy cost : fix (€/y)	250,00 €		400,00 €		0,00 €		0,00 €		500,00 €	
Other energy cost : variable (€/MWh)	130,00 €		130,00 €		0,00 €		0,00 €		110,00 €	

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	ROMANIA - BUCHAREST					
	Individual house(150m2)		Office(4442m2)		Commercial center(27000m2)	
Heating needs (MWh/y)	11,468	11,468	270,00	270,00	2500	2500
Cooling needs (MWh/y)	1,785	1,785	187,5	187,5	900	900
Process needs (MWh/y)					1675,52	1675,52
Efficacity (heating)	0,98	4,7	0,98	4,5	0,98	4,5
Efficacity (active cooling)	3	6	3	7,5	3	7,5
Efficacity (passive cooling)		30		30		30
Ratio of active cooling	100%	20%	100%	50%	100%	50%

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Investment cost (€)	7 000,00 €	12 000,00 €	84 400,00 €	210 608,00 €	282 000,00 €	977 640,00 €
Maintenance cost (€/y)	150,00 €	100,00 €	2 500,00 €	1 500,00 €	24 000,00 €	12 000,00 €

Electricity cost : fix (€/y)						
Electricity cost : variable (€/MWh)	200,00 €	200,00 €	200,00 €	200,00 €	200,00 €	200,00 €
Other energy cost : fix (€/y)	0,00 €					
Other energy cost : variable (€/MWh)	75,00 €		75,00 €		75,00 €	

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	FRANCE - PARIS									
	Individual house		Collective (residential) building		Office		Commercial center		Health facility	
Heating needs (MWh/y)	11,468	11,468	83,9	83,9	154,186	154,186	416,88	416,88	180	180
Cooling needs (MWh/y)	1,785	1,785	17,85	17,85	137,945	137,945	418,88	418,88	24	24
Process needs (MWh/y)							1675,52	1675,52	80	80
Efficacity (heating)	0,98	4,5	0,98	4,5	3,28	4,5	3,28	4,5	3,27	4,5
Efficacity (active cooling)	2,8	6	2,8	6	2,86	6	2,86	6	2,97	6
Efficacity (passive cooling)		30		30		30		30		30
Ratio of active cooling	100%	20%	100%	20%	100%	50%	100%	50%	100%	50%

Investment cost (€)	8 830,00 €	35 000,00 €	35 205,00 €	142 500,00 €	98 318,00 €	314 500,00 €	161 568,00 €	671 000,00 €	83 500,00 €	445 500,00 €

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Maintenance cost (€/y)	150,00 €	150,00 €	560,00 €	1 250,00 €	750,00 €	2 250,00 €	1 500,00 €	3 700,00 €	750,00 €	2 650,00 €

Electricity cost : fix (€/y)										
Electricity cost : variable (€/MWh)	198,28 €	198,28 €	198,28 €	198,28 €	165,38 €	165,38 €	165,38 €	165,38 €	331,00 €	331,00 €
Other energy cost : fix (€/y)	250,00 €		113,00 €							
Other energy cost : variable (€/MWh)	161,50 €		105,40 €						105,32 €	

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