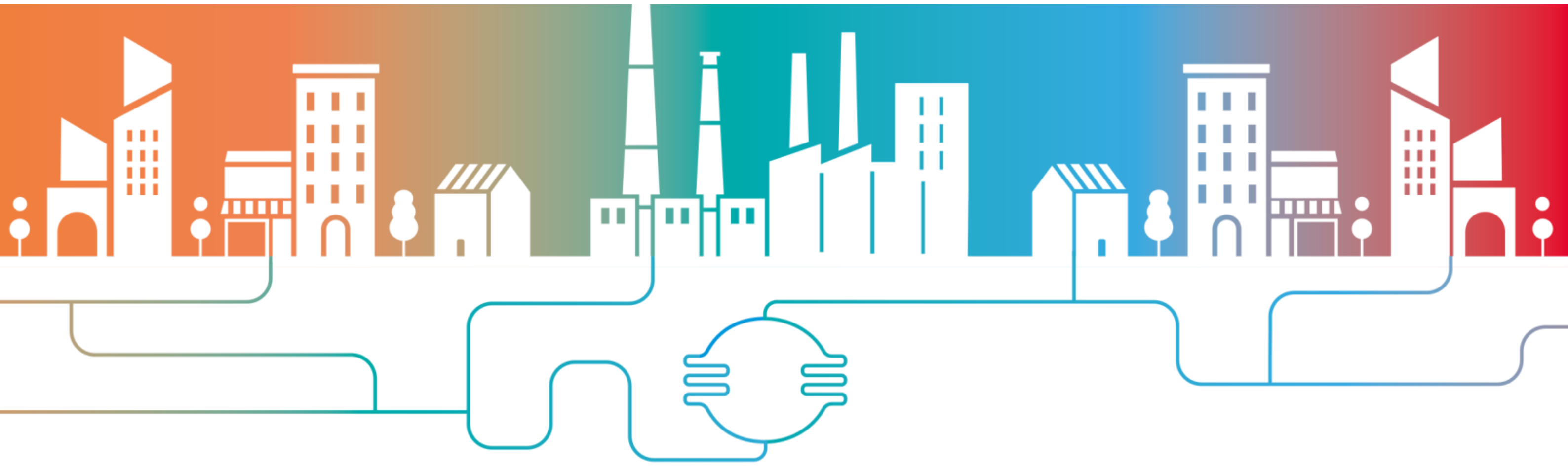
Report on the pre-design studies at the Partner Cities networks – Action C.6.3



Low temperature, urban waste heat into district heating and cooling networks as a clean source of thermal energy

LIFE4HeatRecovery

Project Title: Low temperature, urban waste heat into district heating and cooling networks as a clean source of thermal energy

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1 Introduction

This report of the LIFE4HeatRecovery project focuses on the work carried out in Action C.6.3, where 3 Partner Cities of the projects were analysed, namely Plymouth (UK), Castegnato (Italy), Brunssum (The Netherlands).

The implementation of waste heat recovery measures would be valuable for these Partner Cities. In all cases, such recovery was considered in integration with the local heat networks.

For the case of Castegnato, described in Chapter 2 and jointly analysed by Cogeme and EURAC, both an extension of the network and the inclusion of new waste heat sources was considered. The analysis took into account the constraints between the current generation capacity, the network transmission capacity, and the number of new connected users, keeping attention to feasibility. Both high- and low-temperature waste heat sources were identified (applying the GIS mapping tool developed in Action C.6.4 of LIFE4HeatRecovery). While high-temperature sources are more economically convenient than low-temperature ones (as the formers do not require heat pumps), the inclusion of a certain amount of low-temperature waste heat proved to be crucial to achieve competitiveness against individual heat pumps (the most likely alternative solution to district heating for the case of Castegnato). This is thanks to the different availability pattern among the two types of waste heat.

For the case of Plymouth, followed by KWA, a cold network was considered, involving facilities like a local Pavillon – including a little ice rink – and a Hotel, coupled with aquifer wells. Chapter 3 reports a techno-economic analysis for this case. The heat recovery from the ice rink turned out to be more economically convenient than aquifer wells, providing a valuable input for the project owners. For the case of this partner city, a focus on possible pricing models was also provided.

For the case of Brunssum, presented in Chapter 4 and analyzed by Mijnwater, the needs of the local network were considered as a starting point. Here, ground wells are the main source for the system. Legal requirements however impose a minimum balancing between heat extraction and injection, achievable through a combination of heating and cooling. To this purpose, the use of waste heat plays a crucial role. The case of a local industrial bakery was considered. The promising numbers led Mijnwater to contact the food manufacturing company for a preliminary discussion, though so far the company availability to act as a source was not obtained. A second case, regarding a wastewater treatment plant located in the nearby municipality of Hoensbroek, was also described. For this case, letters of interest among the involved stakeholders have already been exchanged and contacts are ongoing.

In general, the replicability of the low-temperature waste heat recovery solutions proposed in LIFE4HeatRecovery seems quite feasible, with frequent cases of economic convenience. At the same time, local projects typically show long development times, strongly depending on the need to involve multiple stakeholders and on the presence of more general expansion plans for district heating.

2 Partner City: Castegnato

2.1 Case study description

The district heating network of Castegnato (a municipality in the province of Brescia, Italy) is represented in Figure 1.

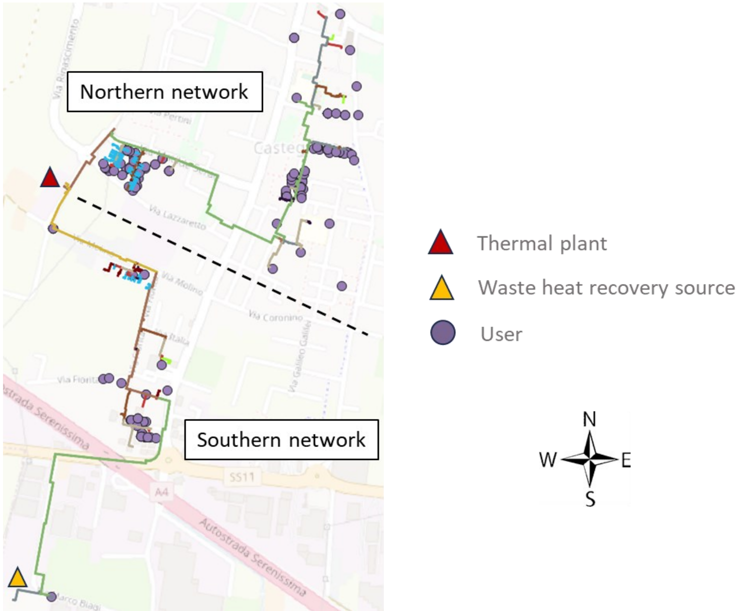

Figure 1 - District heating network in Castegnato (Brescia, Italy).

The thermal plant divides the network into two sub-networks with a classic tree-like structure – the Northern network and the Southern network.

The thermal plant comprises:

- 1 cogenerator with an electrical capacity of 526 kW and a thermal capacity of 671 kW
- 1 gas boiler with a capacity of 2200 kW
- 1 gas boiler with a capacity of 1700 kW

The total installed thermal capacity is 4.571 MW.

In the southern part of the district heating network, there is a waste heat recovery exchanger from the Reboldi foundry, with a size of approximately 600 kW. The foundry has been inactive throughout 2022 due to a bankruptcy procedure triggered by the pandemic crisis, and its resumption of activities is uncertain. Consequently, the network cannot benefit from the related waste heat.

The district heating network is a conventional one, through with relatively low supply temperatures, ranging from 65 °C to 75 °C depending on the season. The number of connected users is 222 (2022 data), categorized into residential, industrial, and tertiary sectors. The majority of users (182 out of 222) are residential, pertaining to newly built single-family homes equipped with a 30 kW heat exchanger based substation. The largest substation, with a capacity of 450 kW, belongs to an industrial user.

Monitoring data for the year 2022 reveals a heat production of 5.7 GWh, out of which only 3.05 GWh are sold to users. The overall heat losses represent approx. 46 % of the production, constituting the primary cause of the high inefficiency of the district heating system (overall efficiency of about 37 %, computed as the ratio between the heat sold and the consumption of primary energy from natural gas). Another disadvantage is associated with the heat sources: all heat production relies on fossil fuels (cogenerator and gas boilers).

The system's inefficiency resulted into an economically uncompetitive heat selling tariff for users and a challenging economic balance for Cogeme (which is the network operator).

To enhance the environmental and economic sustainability of the system, it is essential to progress simultaneously on two fronts: the addition of new customers and the integration of waste heat sources. These interventions would reduce both the weight of the network heat losses and the reliance on fossil fuel sources for heat production, thus promoting a trend toward lower Levelized Cost of Heat (LCoH).

To this purpose, the implementation of a new, low-temperature subnetwork was initially considered, driven by the return pipeline of the existing conventional network. The new network branch was considered mainly to distribute heat to the town's industrial area, in the southern part of the city. During the analysis, however, the industrial area was realized to offer some interesting high-temperature waste heat sources. Under such conditions, in order to avoid degrading such heat, it is more efficient to keep the network at high temperature. The idea of a low-temperatures subnetwork was hence abandoned (also considering that the operating temperature of the existing network is anyway relatively low, see above). Nevertheless, the attention to low-temperatures waste heat was maintained. The following analysis provides an overview of the identified possibilities and how, even in a context with available high-temperature waste heat, low-temperature waste heat remains valuable as well, especially for the different (and in this case somewhat complementary) availability pattern.

2.2 Waste heat integration

2.2.1 Waste heat sources mapping

Waste heat mapping was carried out by using the tool developed by EURAC in Action C.6.4. In particular, the methodology described was applied for all the companies in the municipality of Castegnato and surrounding areas.

Figure 2 shows the results obtained from the mapping tool (more than 300 companies have been investigated).

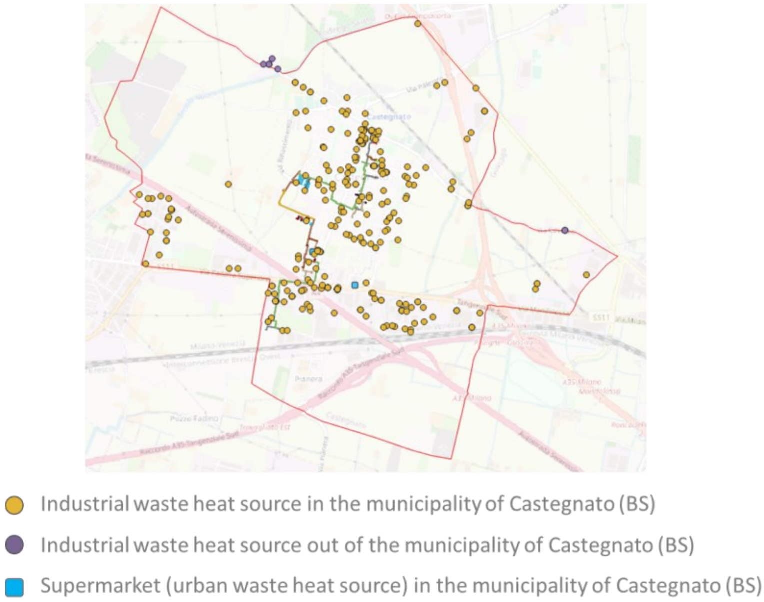

Figure 2 - Waste heat sources mapped for the case study of Castegnato (Brescia, Italy).

Given the large number of mapped companies, a filtering analysis was conducted in order to focus only on the most interesting ones for a connection to the district heating. The **selection criteria** adopted to filter the number of companies are given in Table 1.

Table 1 – Selection criteria for filtering waste heat sources.

Criteria	Notes
NACE code	From the data analysis, companies with the following NACE codes are of particular interest for potential waste heat recovery: • Food industries – NACE code 10 • Chemical industries – NACE code 20 • Glassware – NACE code 23 • Metal sector – NACE code 24 and 25
Company size	For each NACE code of interest, the largest companies were selected. Size was assessed both by the number of employees and by means of a virtual inspection via Google Maps. The latter aimed to assess the real size of the building and to distinguish operational from legal sites.
Proximity to the district heating network	All potentially interesting companies located too far from the district heating network were excluded from further analysis.

Applying the selection criteria illustrated above results in a considerable reduction in the number of waste heat sources considered of real interest for a further in-depth analysis, decreasing from the over 300 mapped companies to the 8 companies shown in Figure 3.

Figure 3 – Potential waste heat sources for district heating in Castegnato.

Table 2 shows the quantitative results of the estimated waste heat (WH) availability for the selected sources.

Table 2 – Estimated waste heat availability for the selected sources.

General information		WH availability [MWh/y]			
Company	***WH typology***	***Low-T***	***Med-T***	***High-T***	***Total***
Ghial	Industrial (foundry)	210.1	944.7	64.1	**1358**
G.M. Plast	Industrial	575.0	808.9	1329.7	**3096**
Alutherm	Industrial	68.9	310.0	21.2	**446**
ODS store	Urban (bakery)	197.8	110.3	187.8	**628**
Panificio F.	Urban (bakery)	197.8	110.3	187.8	**628**
Prix	Urban (supermarket)	987.7	/	/	**1646**
Gnali P.	Industrial	23.3	43.3	3.3	**85**
Effedue	Industrial (foundry)	(*)			**1143**
Reboldi (**)	Industrial (foundry)	(*)			**3450**

(*) The waste heat availability is provided by Cogeme.

(**) The Reboldi foundry is already connected to the district heating network but has been inactive in recent years and will presumably remain so in the near future.

To recover the low-temperature waste heat within the district heating network, an upgrade of the thermal level is required; this can be done by a heat pump. For this reason, the total availability of waste heat is calculated according to the following equation:

$$\mathrm{WH_{tot}} = \mathrm{WH_{low-T\,corr}} + \mathrm{WH_{med-T}} + \mathrm{WH_{high-T}}$$

Where:

$$WH_{low-T\,corr} = WH_{low} \cdot \left(1 + \frac{1}{COP_{ref} - 1}\right)$$

For the heat pump a reference COP of 2.5 was conservatively used to get Table 2 total values.

The results show that, in addition to the Reboldi foundry, there are approx. 9 GWh/y of other waste heat at the thermal level of the network. This quantity would be sufficient to cover all current heat production (about 5.7 GWh/y). However, the temporal profiles of waste heat availability and heat demand of the network are not perfectly contemporaneous. This aspect significantly reduces the amount of waste heat that can actually be recovered in the network, as shown in the next section.

2.2.2 Integration of waste heat into the district heating network

By comparing the hourly profiles of required heat production and availability of waste heat from the different sources, it is possible to estimate the amount of waste heat that is actually recovered in the network and, therefore, the amount of heat that must instead be produced by the fossil fueled thermal plant.

This analysis was conducted for the following two scenarios:

- Scenario A (more optimistic)

  All the companies identified as potential sources in the waste heat mapping phase were considered, except for the Reboldi foundry. ***Total waste heat availability: 9.01 GWh/y.***

- Scenario B (more realistic)

  Of the potential sources identified, the most interesting in terms of potential connection to the district heating network were selected: Ghial, Effedue and Prix supermarket. ***Total waste heat availability: 3.8 GWh/y.***

Figure 4 shows the results obtained from the comparison of the hourly profiles for the two scenarios.

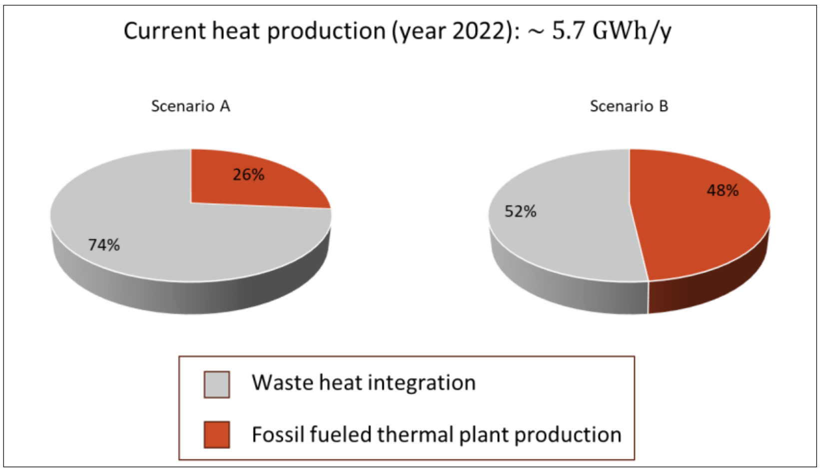

Figure 4 – Decarbonisation of heat production in the scenarios investigated.

It emerges that, even in scenario A in which the availability of waste heat (9.01 GWh/y) exceeds the total heat demand of the network (5.7 GWh/y), heat production cannot be decarbonized completely (but only up to about 74 %) because of the lag between the availability and demand profiles. In the more realistic scenario B, a waste heat penetration of approx. 52 % of the current total heat production is achieved. In scenario B, two high-temperature industrial waste heat sources (Ghial and Effedue) were considered. For these foundries there is only availability of waste heat from Monday to Friday, thus leaving all weekends uncovered. On the other hand, **the Prix supermarket presents a continuity of operation throughout the week**, thus being of considerable help in improving the efficiency of the system.

Thus, although low-temperature waste heat has the disadvantage of needing a heat pump to be recovered in traditional district heating networks, the greater temporal continuity of availability makes it of considerable importance for the efficiency of district heating systems by avoiding the need of short- or long-term thermal storage.

2.3 Environmental analysis

Monitoring data from the year 2022 showed that from an environmental point of view, the current district heating configuration is not competitive. Indeed, it resulted a Primary Energy Factor (PEF) of approx. 2 and an Emission Factor f_{DH} equal to $0.44\ \mathrm{t_{CO2}/MWh}$.[1]

For the scenario B (discussed in the previous section), the results of an hourly simulation model show a significant improvement of the system from an environmental point of view: thanks to the integration of waste heat, the PEF is reduced to 1.16 and the emission factor is reduced to 0.24.

Despite the clear improvements, if one compares the PEF obtained with the typical value of an individual heat pump (around 0.6-0.7), one finds that to achieve environmental competitiveness, larger amounts of waste heat must be integrated. Besides waste heat integration, the addition of new users in district heating can also contribute to reducing the PEF as the percentage weight of network heat losses is reduced.

For this purpose, an analysis was conducted to investigate how much heat can be additionally sold considering the current district heating configuration unchanged.

2.3.1 Estimation of possible new heat selling with the current district heating configuration

To estimate the additional amount of heat that can be sold with the current district heating configuration, the following constraints are considered:

- heat demand of users not connected to the network and at a maximum distance of 100 m from it (this limits the analysis to the users located in proximity of the network)
- heat transmission capacity of the network with its current structure
- heat production capacity of the thermal plant

To estimate the heat demand of unconnected users, a heat demand per unit area of $105\ \mathrm{kWh/m^2/y}$ has been considered. The value is obtained as the arithmetic average of the annual specific heat demand for old residential buildings (110 for space heating + 20 for domestic hot water) and new residential buildings (60 for space heating + 20 for domestic hot water). Thanks to the available GIS mapping files, it was possible to estimate the surface area of unconnected buildings to the district heating network within a maximum distance of 100 meters (conservatively, all buildings were assumed to have one floor).

The heat transmission capacity of the network was estimated based on the average operative temperature difference of the network and the nominal fluid flow rates (data on pipe diameters were provided by the network operator).

The heat production capacity of the thermal plant was calculated by applying the normalized hourly profile of the heat production (estimated based on the data provided by the network operator and the hourly external temperature profile) and scaling it relative to the installed thermal power of the cogenerator and the two gas boilers (0.671 + 2.2 + 1.7 = 4.571 MW).

The most restrictive limit turned out to be the heat production capacity of the thermal plant. Considering uncertainties in hourly profiles and the fact that the analysis is based on 2022 data, which

[1] To compute the PEF, a national electricity efficiency of 0.877 for Italy is considered. The value is based on ISPRA data updated to 2020. The national electricity efficiency is defined as the ratio between the electricity consumed by a final user and the non-renewable primary energy used for its production. The PEF for the natural gas is assumed equal to 1.
Emission factors: for the natural gas is assumed equal to $0.205\ \mathrm{t_{CO2}/MWh}$; while for the electricity is $0.260\ \mathrm{t_{CO2}/MWh}$ according to ISPRA data updated to 2020.

presented a relatively mild climate compared to the average, a reduction coefficient of 50 % was applied.

The final value obtained for the possible new heat selling is **1.6 GWh/y.**

2.3.2 Parametric analysis for environmental competitiveness

The waste heat mapping process showed that potential waste heat sources have an availability of about 9.01 GWh/y at high temperature (of which 7.4 GWh/y are already available at high temperature while about 1.65 GWh/y come from the PRIX supermarket, which is a low-temperature waste heat source).

To achieve environmental competitiveness with individual heat pumps, a parametric analysis is carried out in which the PEF is calculated with increasing availability of High-Temperature Waste Heat HTWH. To assess the benefits of integrating the low-temperature waste heat source (PRIX supermarket), the same analysis is carried out for two different scenarios: without and with the integration of PRIX supermarket into the district heating network.

The quantity of heat sold (total users heat demand) is used as the curve parameter. The latter is varied from a minimum of 2.6 GWh/y (because on the network operator's recommendation, one of the connected schools will be moved to another location from next year which is not connected to the district heating, thus approximately 0.4 GWh/y will be lost compared to the current heat demand) to a maximum of 8.75 GWh/y (value compatible with the network's transmission capacity but exceeding the production capacity of the fossil fuelled thermal power plant. This was done because the presence of a certain number of waste heat sources will in any case allow greater flexibility in managing peak demand).

In both scenarios, for curves referring to high demand and low values of high-temperature waste heat availability, the current thermal power plant would not be able to satisfy all heat demand. Thus, to complete the analysis, it is assumed that additional gas boilers (with the same efficiency as the present ones) would be installed as supplementary heat generators.

The hourly profile for high-temperature waste heat is available from Monday to Friday, while at weekends it is deactivated. Instead, the hourly profile for low-temperature waste heat from PRIX supermarket is available for the entire week, weekends included.

Figure 5 shows the results obtained from the analysis performed in the scenario without the integration of PRIX supermarket as low-temperature waste heat source.

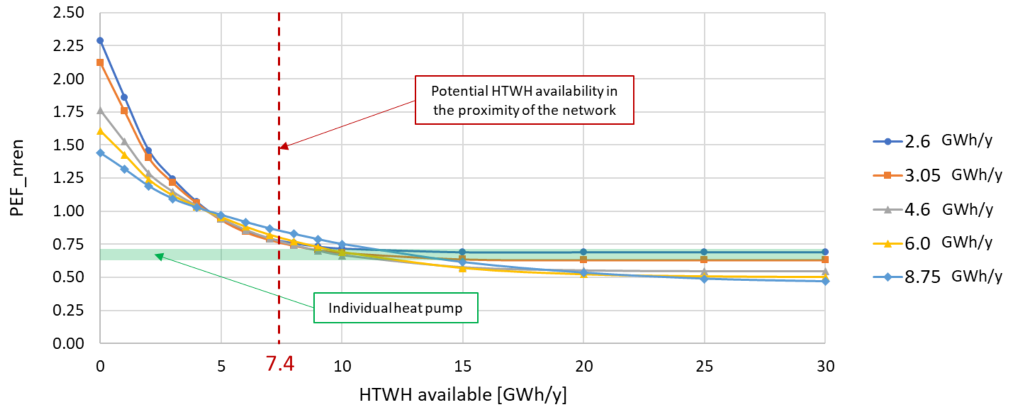

Figure 5 - Parametric analysis on the integration of HTWH to achieve environmental competitiveness with individual heat pumps (scenario without PRIX supermarket).

In the scenario without PRIX, regardless the total users heat demand, it is observed that environmental competitiveness with individual heat pumps is achieved for a high-temperature waste heat availability of about 10 GWh/y. However, this amount is not available in the proximity of the network, but sources at greater distances would have to be integrated, thus requiring greater economic investment.

The main obstacle remains weekends: heat demand at weekends cannot be met by waste heat because there is no availability. This leads to some unavoidable utilisation of the fossil fuelled thermal plant and thus to a worse PEF.

The integration of PRIX supermarket makes it possible to cover part of the users heat demand at weekends. This allows a reduction in the natural gas consumption of the thermal plant. As shown in Figure 6, the integration of the supermarket makes it possible to lower the needed HTWH to be integrated into the district heating system in order to achieve environmental competitiveness with individual heat pumps to values compatible with the potential availability in the proximity of the network. This is not true only for the case with the highest users heat demand (8.75 GWh/y) because, as in this case the heat demand is very high, the percentage covered by waste heat is still too low.

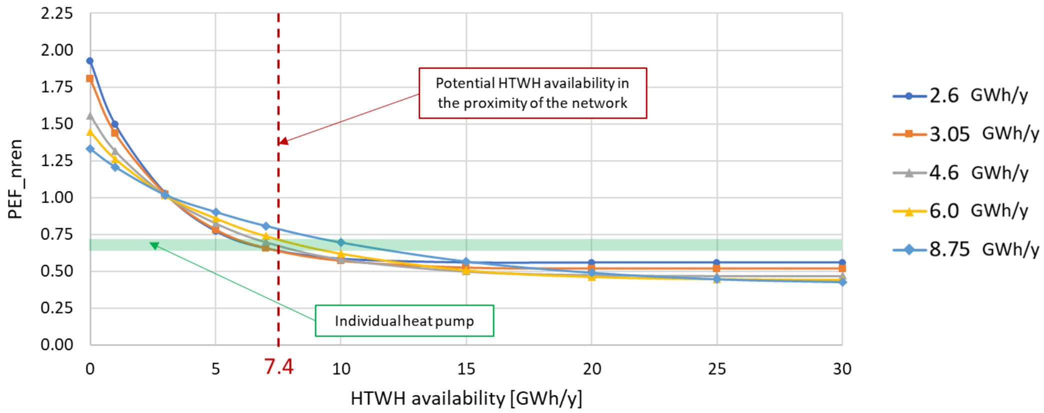

Figure 6 – Parametric analysis on the integration of HTWH to achieve environmental competitiveness with individual heat pumps (scenario with PRIX supermarket).

The results of the analysis confirm the importance of integrating low-temperature waste heat sources also into traditional district heating networks as already mentioned.

2.4 Economic analysis for the integration of low-temperature waste heat

From an economic point of view, high-temperature waste heat is generally more competitive than cogeneration. In fact, typically the price of waste heat, if any, does not have high values. In the case of low-temperature waste heat in traditional networks, one must also consider the investment cost and the electricity consumption of the heat pump needed for the temperature upgrade.

In this regard, an estimation of the levelized cost of heat is provided for both the low-temperature waste heat and the cogenerator. The estimation is based on the parameters given in Table 3.

Table 3 – Economical parameters for LCOH calculation.

General parameters		
Interest rate	6 %	
Electricity price (buying)	210 €/MWh	
Electricity price (selling)	95 €/MWh	
Gas price (buying)	90 €/MWh	
	Heat Pump	**Cogenerator**
Unitary cost	0.50 M€/MW	0.89 M€/MW
Operation and Maintenance cost rate	5 %	6 %
Lifetime	25	25
Equivalent hours	2000	3000
COP	3.5	/
Thermal efficiency – Electrical efficiency	/	0.5 – 0.4
LCoH operating	***58.8 €/MWh***	***104.0 €/MWh***
LCoH total	***90.9 €/MWh***	***145.2 €/MWh***

The operating LCoH differs from the total LCoH by not taking depreciation rates into account.

The energy prices used are based on forecasts made by Cogeme. The value used for the heat pump COP refers to a temperature lift from 20 °C of the heat source to 70 °C of the heat sink. The unitary cost and the efficiencies of the cogenerator are assumed equal to the data provided by Cogeme. For the heat pump unitary cost, a rather optimistic values as been assumed, considering the standardization pursued by this project. Without standardization, costs of 1 M€/MW can be assumed, which still keeps low-T WH combined with HPs competitive with cogeneration.

From the obtained results, it is evident that the integration of low-temperature waste heat also in traditional district heating systems is highly competitive with the cogenerator on an economic point of view. This demonstrates its attractiveness not only in terms of environmental benefits, but also in economic terms, by allowing lower end-user prices for heat sales and thus being more competitive with other individual solutions (e.g., individual heat pumps).

3 Partner City: Plymouth

3.1 Description of the Case Study

As many more cities, also the City of Plymouth is looking forward to support ecological solutions incentivizing the development of innovative zero combustion systems of heating and cooling. One of the projects, which serve this target, is the heating and cooling supply of the Plymouth Pavilions, the new Moxy Hotel (currently in construction) and the new Plymouth City Homes district, which includes about 150 residential units. The system is also potentially connectable to the Ballard House as well as into the city centre. Through this system energy sharing, recycling and potentially storing between the season would be allowed.

In this case study, the inclusion of waste heat usage from the ice rink of the pavilion will be elaborated and added to the existing feasibility studies from 2020. Based on the costs of this network, and savings by using waste heat from the ice rink a top-level economic performance evaluation will be developed. Therefore, different possible pricing models will be elaborated to find a price structure which is attractive to the future customers.

During the process of this case study a feasibility study from 2020 was extended to proof assumptions and get more detailed information. It was shown that the planned aquifer wells do not deliver as much energy as needed, which makes the project less bankable as more wells have to be drilled. Therefore, a study to use seawater heat pumps is ongoing. Due to the limited available data, it was not possible to include here numbers or ideas of sea water heat pumps, though general conclusions about waste heat are expected to remain valid.

As the target and main need of the City of Plymouth was to evaluate different pricing scenarios, only a rough calculation has been made for the whole system to show the benefit of using waste heat.

3.2 Identification of the technical solution

3.2.1 Set of analysed configurations

In order to install a 5th Generation District Heating and Cooling network, the buildings participating to the network have to be defined. The main buildings, which will be connected are the Plymouth Pavilion, the new Moxy Hotel and the new Plymouth City Homes district. The other facilities could be added to the network are not involved in this case study. The case study of 2020, made available by Plymouth partners, already analysed if the aquifer yield is adequate to meet thermal demands and if the system is pre-qualifying for the Renewable Heat Incentive (RHI) support by March 2021 with commissioning of the systems by 2022.

During the elaboration of this report the funding and incentive schemes changed and the thermal elaboration of the aquifer yields had shown that the sources do not meet the demand of the buildings. To meet the demands more bore holes have to be drilled or different sources have to be added. In this case we compared the costs by drilling more holes to the use of waste heat from existing sources.

As our main target of this case study is to show up different price models and the influence of the waste heat source, it was decided to use the numbers given in the existing feasibility study.

Figure 7 - Main buildings for the Plymouth project.

The Pavilions is an event space with offices and an ice rink. The entire heat demand of this structure is covered by the boiler plant via a plate heat exchanger located in the boiler plant room. The cooling demand especially from the ice rink, is covered by the recently installed chillers via distribution pumps. In this case study these chillers will be the waste heat source for the network.

The Moxy Hotel will be built on the green site and showed interest in getting connected to the network. As it was not yet built at the time of this analysis, just assumed numbers are given and the amount of waste heat by the cooling machines cannot be quantified in detail. For similar reasons, the hotel was not included in the case study as a waste heat source, though in principle it has a certain potential in this respect (due to its cooling needs).

About the Plymouth Community Homes, only little information was available, as the development plans were not finalised. This gives us the same basis as the Moxy hotel. But based on the already conducted investigations by the 2020 study, the heating and cooling demand of the main cluster is roughly known and can be looked up in the following table.

Table 4 - Annual cooling and heat demand of the main buildings

Building	Annual Cooling demand	Annual heating demand
Plymouth Pavilion	0.77 GWh	1.34 GWh
Moxy Hotel	0.22 GWh	0.44 GWh
Plymouth Community Homes	0.33 GWh	0.74 GWh
In Total	1.22 GWh	2.52 GWh

3.3 Performance evaluation

3.3.1 Technical performance evaluation

To support the heating demand of the network a certain number of aquifer wells must be connected. The target of the waste heat source is to decrease investment costs by replacing some boreholes with a cheaper heat source. Therefore the cooling equipment of the existing ice rink in the Plymouth Pavilions has been identified. To elaborate the investment costs of the waste heat source this case study falls back on the elaboration of the energy consumption of standardized ice rinks from the International Ice Hockey Foundation (IHF) in 2016.

The size of the ice rink of Plymouth is estimated a third of their size of a standardized ice rink as it is not used for official hockey games but only for leisure. In the IHF Ice rink guide it is reported that the ice rinks can use the waste heat from the cooling machines to cover the yearly need of the heating demand and more. For our purpose the numbers of a case located in Munich have been used as the average yearly temperature comes closest to the temperature of Plymouth. In the red dashed line in Figure 8, the amount of heat from the refrigeration condensers can be seen, while the red line shows the heating demand of the ice rink. Calculated over the year, about 1100 MWh of heat is needed while about 2300 MWh heat is produced by the condensers. This results in about 1200 MWh of waste heat which can be used inside the network.

As the ice rink has about a third of the size of the ice rink of Munich, 0.4 GWh of waste heat can be included inside the network of Plymouth which is about 17 % of the demand of the network.

It has to be pointed out that these are just rough values and topics like the simultaneity factor and load demands during peak hours have been neglected.

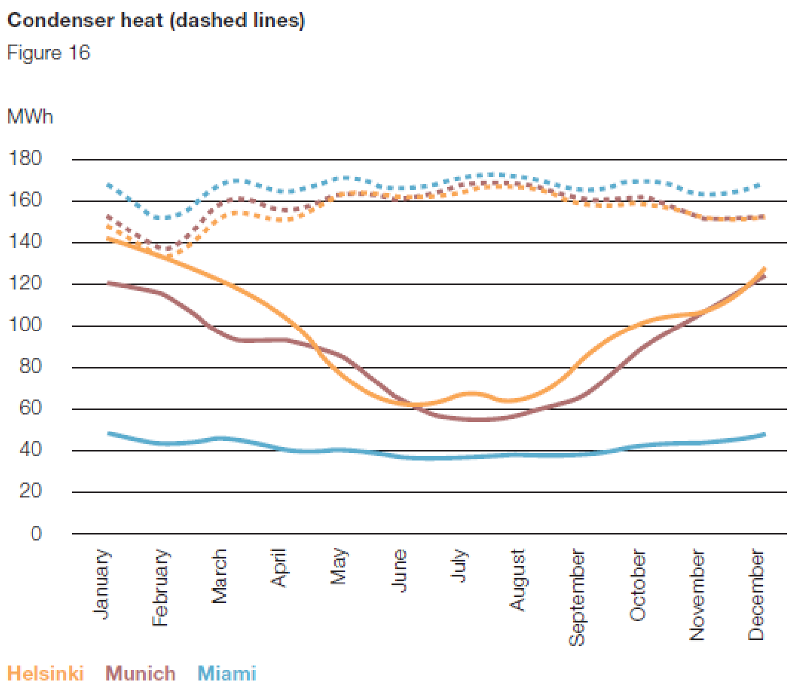

Figure 8. Heating energy need of ice rink and het from the refrigeration condensers.

3.3.2 Economic performance evaluation

From the numbers received from Plymouth and the 2020 case study the capex for the boreholes and the connection to the network was estimated on 1,513,000 €. With a total heat production of 50,400 MWh over 20 years it results in heating costs of 30,01 €/MWh. These costs do not include the network, connections to the buildings, pumps and controlling equipment which helps us to get comparable numbers for the waste heat source.

To receive a comparable number of the capex of the waste heat source, it was decided to call in numbers from the early adopter study of Schwaigern (where heat recovery from supermarket into a cold network was considered, therefore with similar boundary conditions). In this case study the waste heat was also used from refrigerant condensers and had the same amount than the estimated waste heat from the ice rink. In Schwaigern a capex of 33,000 € was set for an amount of 8,000 MWh over 20 years which results in energy production costs of 4,13 €/MWh.

Setting both numbers in comparison, one can see that the investment costs of the boreholes are about 7.5 time more expensive than using waste heat from the ice rinks. Even with estimated numbers and some missing components like simultaneity factor, it is clearly shown that the use of waste heat should be included not only from an environmental perspective, but also from an economic one.

3.4 Energy pricing models

As the plan is to install a 5th Generation District Heating and Cooling network, heat pumps are needed to cover the whole energy demand of the users. To develop different pricing models the inclusion of different energies must be defined, and several options of delivery borders have to be mentioned. Besides a model where the network owner owns the whole system including heat pumps, there is also the possibility to place the heat pumps in the ownership of the users/participants. In the following sections different pricing models based on different delivery borders are shown. This analysis was carried out to meet the explicit interest expressed by Plymouth project stakeholders.

Additionally, there will be solutions to decrease investment costs by construction cost subsidies, connection fees or funding as part of the pricing models.

3.4.1 Pricing models including heat pumps

In this scenario it is assumed that the whole network including the heat pumps are owned by one company. This gives the network operator the chance to manage the whole network and gives the opportunity to optimize the operations. On the other hand, it also increases risks. Investment costs are higher for the operator, the system gets more complicated to manage and if the consumption decreases due to energy efficiency measures at the user sites the project gets les bankable. The use of electric power also introduces risks related the price uncertainties.

a) Base price including price per kWh

With the delivery border after the heat pumps different costs have to be included. On the one hand, there are fixed costs which are not dependent on the amount of energy delivered, while on the other hand there are cost dependent on the energy amount. The first group includes topics like interest and repayment of the investment costs, personnel, controlling, administration and parts of the maintenance which have to be replaced anyway. These costs are so called fixed costs. The second part includes the electricity costs for the heat pumps and distribution pumps and the maintenance of those parts. Additionally, there will be parts which might have to be maintained more if the network is more occupied. Those costs are called flexible costs.

Therefore, it makes sense to split the energy price for the customer into two parts. One part should cover the fixed costs while the second part covers the flexible costs. The fixed costs are usually based on the maximum load the participant needs. In case of the Pavilions this can usually be measured during the time of construction. In case of the new buildings, estimates have to be used and maybe updated after year one or year two. Another possibility could be to set ranges: e.g., every customer till 10 kW has to pay a certain price, every customer till 50 kW has to pay another price per year and so on. The ranges have to be set individually for each project. The flexible costs have to be covered by a flexible price per kWh. This price should be the same for each customer inside the network and has to be connected to a price escalation clause. The price escalation clause usually includes different factors connected to the market situation, salary and price of the energy source. The target is to lower the effect of fast changing costs (cut the peaks) and to participate the customers with rising energy costs but also with falling energy costs.

All in all, the project has to be calculated well as the pricing scheme includes different cost aspects as well as the energy price. Especially the estimates of the demand of the customers have to be calculated well. In the calculation, the costs of a certain lifetime (e.g., 20 years) have to be split up in fix costs and flexible costs to calculate which prices the customers can be offered. If the costs and the revenues of the two pricing parts do not match, the risks of a miscalculation due to lower demand than estimated rise. On the other hand, the same do the chances for a higher revenue. It is recommended to keep the two parts well balanced, but sometimes the operator must take the risk to match the customer's needs.

3.4.2 Pricing Models if heat pumps are managed and owned by the users

In this model it is assumed that the heat pumps are in the ownership of the participants which simplifies the operations and economic calculation for the network owner. Therefore, it decreases the risks of the project a lot, as investment costs are lower, the network operator is not or way less dependent on electricity prices and has less technical parts to maintain in his ownership. This gives the opportunity for two more pricing models, as even the pricing model from the previous scenario is suitable as well. As the electricity for the heat pumps and thus the main part of the flexible cost fall away, however, these have either to be very low or the network operator takes the risk that electricity prices and therefore the revenues decrease without having the same amount of less costs on the other side.

a) Only base price

With the heat pumps in the ownership of the customers the flexible costs are only a very small part of the pricing model. There is still electricity needed to operate pumps, valves and other controlling components, but these costs just take a very small part of the total costs over 20 years. They will also be very constant and will not have big risks or changes except the price of electricity.

As we now identified the fixed costs as the main part, the idea is to sell the low temperature heat to a yearly base price. The energy of the network has no procurement costs as it comes from the wells and the waste heat. Therefore, it does not matter how much energy a user takes from the network. Anyway, a gradation has to be made like in the first model. It would not be fair if any resident of the Plymouth Community Homes pays the same price as the pavilion or the Moxy hotel. There are different ways to split up the costs. One possibility can be according to connection size; another way is to calculate the costs by the yearly demand; yet another way is to consider the building area (more suitable for residential only applications).

b) Only one average heating price

As most of the customers are used to have a price per kWh, it might be irritating for them to only have one fixed base price per year. Therefore, another option would be, to set the price per kWh. This would entail certain risks and chances. If the total kWh are more than expected, the operator can earn more money, but if the total kWh are less than expected due to global warming or vacant buildings, the revenues can decrease significantly. Furthermore, in this model heat meters have to be installed at every customer place, which is not necessary at the model before.

3.4.3 Possibilities to decrease investment costs

Another topic which is connected to the pricing models is described in this chapter. By decreasing the investment costs, the heat price for the customer can be decreased as well. In the pricing model of section 3.1.1 it will also affect the proportions of the fixed and flexible costs. All topics can be part of the negotiations with a customer, as they can influence the business case significantly and thus the energy price as well.

a) Connection fee

The most common way in a network to generate additional revenues is to charge the customers a connection fee. The connection fee is a one-off amount paid at the beginning, reflecting the investment costs to connect the customer to the network. This is similar to the investment cost users would have to pay if they were not connected to the network and needed to buy their own heating and cooling system. Consequently, an appealing connection fee should be lower than the investment costs for the customer if they built their own system. From a top-level view, it is only a shift of the date and duration on which the customer has to pay, but it can make a difference in interests and also in customers mind.

b) Construction cost subsidy

If one of the users focuses on low energy prices it is possible to support the network owner by paying a construction cost subsidy. This might be the case if the subsidy is seen as a small part of the investment costs of a new building like the Moxy hotel and the focus is to have fewer running costs during the operation. It always depends on the participant and their financial status. For participants who do not have the capital to pay such a subsidy or if the focus is not on low energy prices this model is not suitable. This can be the case for real estate companies which rent the flats and houses and do not have to pay the energy bills at the end.

c) Funding

A further but less frequent possibility is to participate at a funded research project like LIFE4HeatRecovery. As part of such a research project it is possible to get funds for the development of the system and also the investment. Anyway, it is not easy to find the right and fitting research project in the right time. Additionally, it is usually a chance for one project but hard to copy or adopt for future projects.

d) Investment grant and incentives

More long-term potential is offered by government fundings and incentives programs. Unfortunately, in the case of Plymouth the fitting program expired before the realization of the project took place. However, often new programs start and eyes should be kept open to find fitting opportunities to get supported in investment costs or incentives during the operation of the system.

3.5 Final remarks on Plymouth case

In the interaction between LIFE4HeatRecovery and the City of Plymouth two needs of the city of Plymouth have been identified. One was with a technical focus (selection of waste heat sources) and the other was with an economic focus (pricing models). As the leading partner for this case study was KWA, with a stronger expertise on the economic side, a higher attention was given to the latter.

Concerning waste heat, an ice rink was identified as a fitting source. It was possible to calculate an estimated energy production price and compare this price with the energy production price of the aquifer wells. It was found that the waste heat source is significantly cheaper than the wells.

Concerning pricing models, different ownership structures were considered. For a project still in the planning stage, the delivery borders are indeed often not yet set. This gives the network operator the possibility to choose between different models. For 5th generation networks, if the delivery border is behind the heat pumps then electricity costs will play a significant part in the operator economic calculations and also in the pricing models. Moreover, the operational effort will rise and heat meters will be needed in every building. A pricing model with the two components base price (€/year) and variable price (€/kWh) is recommended.

If the heat pumps are on the customers side, the system of the operator gets way easier and also the risks decrease. The electricity plays a minor role in the business case and there are almost no variable costs which results in a way easier and more calculatable business case than in the top model. On the other hand, the network operator has less control on the system and on its efficient operation.

Additionally, there are further possibilities which can be included into the pricing model like one-time costs as construction cost subsidies or connection fees.

All in all, it can be said that the usage of waste heat is beneficial for the project and that pricing model are highly dependent on the system and the delivery borders.

4 Partner City: Brunssum

4.1 Case study description

The Tarcicius power plant in Brunssum is supplied by a local WKO system ("warmte koude opslagheat", i.e., heat-cold storage in groundwater). An important condition for the functioning of this type of open geothermal energy system is that the supply of heat and cold is in balance. In Brunssum, more heat is currently being structurally extracted from the hot source (winter) than supplied back (summer), causing an increasing imbalance.

The main causes for this are:

- There is currently (too) little cold consumption by end users (homes)
- There is a continuous heat demand for hot water preparation in the homes

For legal and functional reasons, the WKO must be in balance within 5 years after start-up (on an annual basis). Because the WKO was put into use in mid-2021 according to the Provincial permit, it must be in balance by mid-2026. In order to continue to guarantee the security of supply of the WKO system, an additional facility is required in the short term to restore the balance in the WKO.

<u>Reading Guide for this chapter</u>

Section 4.2 of this memorandum describes the current situation. With regard to the previous problem definition, various studies have already been conducted and solutions explored, looking at reducing the heat demand or sustainably generating heat for source regeneration in the immediate vicinity of the WKO installation. In Section 4.3, the solutions investigated so far are described and the conclusions are broadly summarized. Because none of the solutions examined proved to be feasible, Mijnwater started looking for other solutions in the area, which are described in Section 4.4. Because the realization of such solutions by definition requires longer lead times, a bridging solution is necessary in the short term. This is described in Section 4.5.

4.2 Current situation

The power plant supplies heat and cold through a LT (low temperature) distribution network to a number of clusters of newly built homes owned by the Weller housing association. A total of 191 homes are connected:

- Tarcisius (20 ground-level care homes)
- Suits. Savelbergstraat (37 apartments)
- De Oude Egge (total 134 ground-level homes)

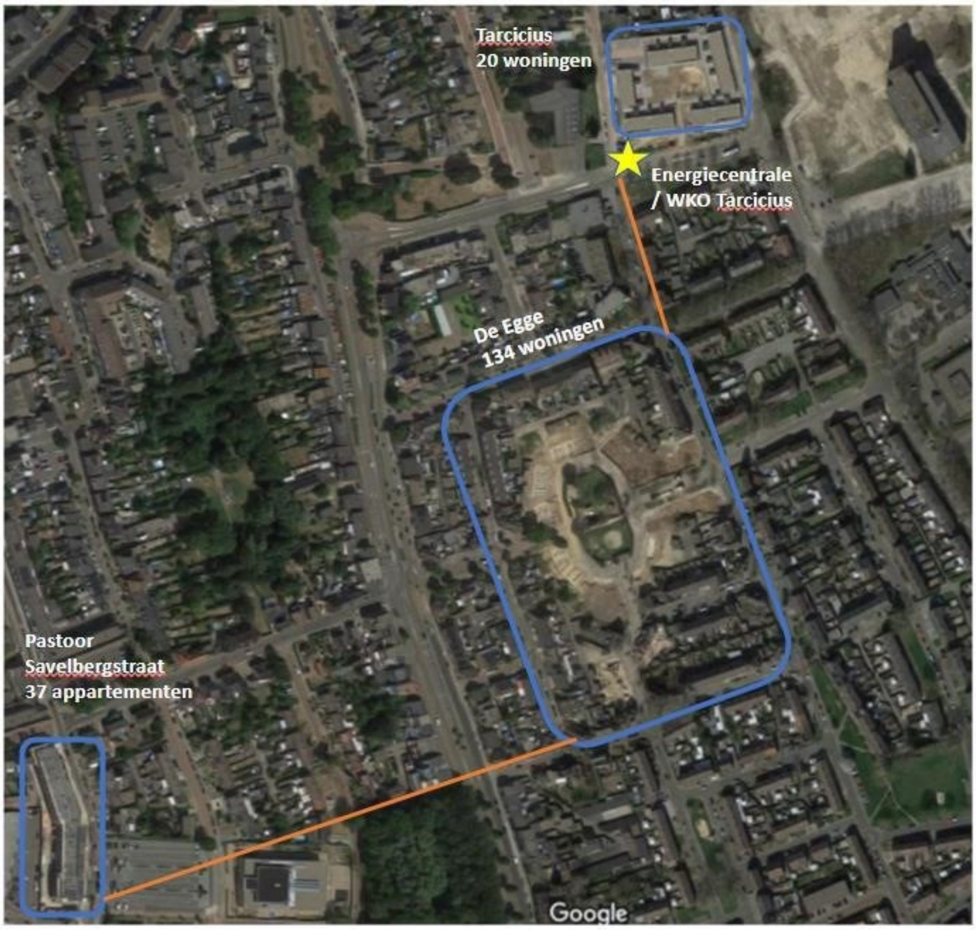

Figure 9. Overview map (source: Google Maps).

Since the commissioning of the WKO system at the EC Tarcisius in mid-2021, an imbalance of more than 4,400 GJ (1.14 GWh) has arisen (situation at the beginning of 2023), which must be restored by reducing the heat demand from the ground sources in the coming years and extracting additional cold.

4.3 Studies carried out

To restore the necessary balance in the WKO system, Mijnwater has investigated various solutions. The starting point was the application of a sustainable solution based on renewable energy sources in the immediate vicinity of the existing WKO installation at Tarcisius.

Minimum requirements for the solutions:

- The source permit allows the hot source to be charged with a water temperature of a maximum of 25°C.
- The power is limited to the source flow of 50 m^3/h, which is approximately 500 kW (for a temperature difference of slightly less than 10 K).
- It must be adjustable, and when sufficient heat has been loaded, it must also be possible to switch it off.

- It must not disrupt the cold supply to the connected complexes/homes.
- Power must be sufficient to meet peak demand in winter.

Based on these principles and requirements, the following solutions have been investigated:

1. Solar PVT panels on Tarcisius
2. Solar PVT panels on Tarcisius / De Parel ("the pearl") shopping center
3. Heat pipes on Tarcicius
4. Dry cooler / air heat pump
5. Asphalt collectors
6. Combination between 1 and 3 Tarcisius
7. Combination between 1 and 4 Tarcisius

The investigated solutions have been assessed based on the following criteria:

- Technical effectiveness (to what extent does the solution contribute to the problem)
- Reliability / operational security
- Technical feasibility
- Impact of implementation on the environment
- Spatial integration into the urban environment (minimal nuisance for local residents)
- Cost

The results of the assessment are summarized in the table below.

Table 5. Assessment of previously considered solutions.

No.	Solution direction	Technical effectiveness	Business reliability	Technical feasibility	Impact on environment	Spatial Integration	Cost	Remark
1.	Solar PVT on Tarcicius	+/-	+	--	+	+	+/-	No permission from Weller to use Tarcisius roofs
2.	Solar PVT on Tarcicius / De Parel	-	+	--	+	+	+/-	No permission for Weller to use roofs, insufficient capacity of existing pipes
3.	Heat pipes on Tarcicius	+	+/-	--	+	+	+	No permission from Weller to use Tarcisius roofs
4.	Dry cooler / air heat pump	++	+	+	--	--	+	Noise/visibility nuisance makes solution unacceptable
5.	Asphalt collectors	+/-	+/-	--	--	++	-	New asphalt / municipal permission required

6.	Combination 1 + 3	+	+/-	--	+	+	+/-	No permission from Weller to use Tarcisius roofs
7.	Combination 1 + 4	+	+	--	--	--	+/-	No permission from Weller to use Tarcisius roofs

Conclusion:

- The majority of the solutions examined appear to be unfeasible because consultation with Weller has shown that, for legal reasons, third-party installations may not be positioned on the roofs of Tarcisius ' care homes.
- The remaining researched solutions are excluded based on suitability / impact on the environment (option 4) or dependence on large-scale adjustment of infrastructure by third parties (option 5).

4.4 Alternative solutions

Because the aforementioned researched solutions have proven to be unfeasible, Mijnwater is currently looking for alternative solutions, primarily looking at options to utilize any residual heat from companies/industries in the area or to sell cold here to maintain the balance in the WKO system. The nearest option for this is approximately 1.1 km from the WKO installation.

Compared to the criteria from the previous section, this solution direction is assessed as follows:

Table 6. Assessment of a general waste heat recovery solution.

No.	Solution direction	Technical effectiveness	Business reliability	Technical feasibility	Impact on environment	Spatial Integration	Cost	Remark
8.	Connection of residual heat	+/-	+	+/-	+	++	--	Cooperation from residual heat supplier / municipality not yet known

Discussions are currently being held with the company in question to explore the possibilities for this solution and to get a better idea of the technical feasibility. Because this solution by definition requires the construction of a distribution pipeline, it must also be taken into account that the realization of such a solution usually takes a minimum of one and a half to two years.

Among the possible waste heat sources, the **VandeMoortele bakery** way investigated with special attention. This is a large industrial bakery with a significant waste heat potential. While at the moment the bakery owner does not seem to be interested in allowing Mijnwater to recover heat, the situation might change in the future and Mijnwater will monitor its evolution. Therefore, the main investigated parameters are reported below, as a representative example of a waste heat source.

Moreover, after the VandeMoortele bakery, a description of the **wastewater treatment plant of Hoensbroek** will also be reported in this section. While this plant plant is not located in Brunssum, it is also representative of one of the options being currently considered by Mijnwater within the Parkstad Limburg region. Hoensbroek, Brunssum, and Heerlen are indeed neighbouring municipalities. In the long term, all these municipalities might be served by the Mijnwater systems.

4.4.1 VandeMoortele bakery

The VandeMoortele bakery is located at Molenvaart 12 in Brunssum. It is a producer of frozen pastry products (flans, cake products, whipped cream cakes, luxurious American style products), among other things.

The floor area is about 7,000 m^2. According to contacts between Mijnwater and the bakery, occurred at the beginning of the LIFE4HeatRecovery project, the production is about 4,396 tons per year, with a gas consumption of about 270,000 Nm^3/y and an electricity consumption of about 4,200 MWh/y.

- The production process consists of:
- A gas-fired oven for product baking.
- A cooling tower for cooling the baked products.
- Two freezing towers to deep freeze the products (in two steps: one at -15 °C, the other at -35 °C).
- C-shock freezers to bring the products to a temperature suitable for them to be cut.

The cooling and freeing processes are done with ammonia chillers. Auxiliary mobile electric chillers are also present.

Within the production process other two steam boilers are present, one for rice and chocolate and one for the crate washing machines.

Air handling units are used for space cooling of production areas. The buildings are only occasionally heated with electric heaters.

Every night production is stopped for a cleaning process (taking approximately 3 hours). This requires hot water (> 65 °C), produced in-house.

Data about the splitting of gas and electricity consumptions were also collected by Mijnwater.

Prosumer substation sizing

Mijnwater considered the possibility to provide both heating and cooling to the bakery, where cooling would correspond to waste heat recovery from the point of view of the network. Considering the above data, the following key figures can be expected:

- Heat supply at two temperatures, namely 45/35 °C and 65/55 °C.
- Cold supply at 12/18 °C.
- Skid with 4 heat pump modules and 2 circulation pumps blocks (primary and secondary side of the network interface),
- Investment cost of the order of 1.2 M€ (a preliminary split between container, heat pumps, heat exchangers, buffers, connections etc. was estimated by Mijnwater).

These data are now considered outdates, therefore if the negotiation with the company will be resumed a thorough update will be required. Nevertheless, this shows the significant potential impact of this source, comparable with the size of the Mijnwater prototype of the Heerlen demo site.

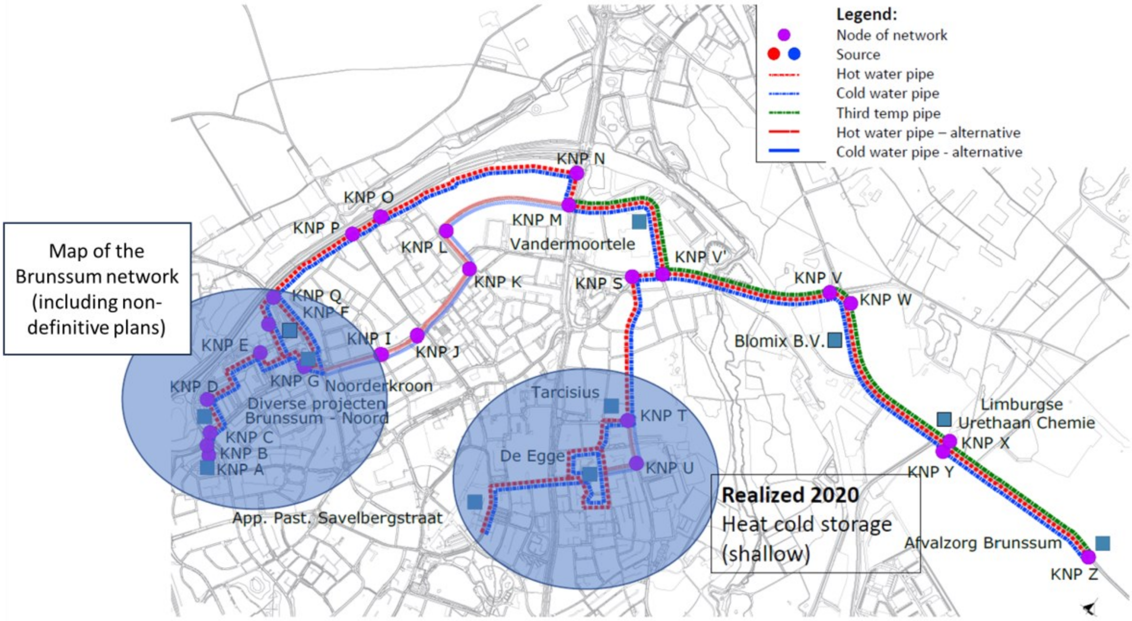

Figure 10. Map of the Brunssum network (including non-definitive plans. VandeMoortele bakery is visible in the middle.

4.4.2 Hoensbroek wastewater treatment plant

Aquathermal energy is the collective term for sustainable heating with process or surface water as a source. WBL, WL and Mijnwater are jointly investigating whether the use of aquathermal energy is promising at the Hoensbroek wastewater treatment plant (WWTP). Heat recovery from wastewater could be an interesting option for an additional heat source for Mijnwater's 5th generation heat network. In addition, surrounding neighborhoods can immediately be supplied with heat in a sustainable and affordable way, via this heating network. Ideally, the ecological condition of the nearby streams can also be improved by cooling the effluent associated with heat recovery.

The three parties have already exchanged a the letter of intent, agreeing to answer 19 research questions until 2024. Based on the insights gained, all parties can work towards a decision point as to whether Hoensbroek aquathermal energy will actually be implemented. Below we provide an overview of the current state of affairs. Two-thirds of the research questions have already been answered positively. The other questions are still being investigated, but no critical issues emerged so far.

Main results of the investigation

The research shows that there is more than enough heat available in the effluent (where water is already clean and no significant fouling issues are expected for heat exchangers) to serve as a source for Mijnwater. The basic principle is that heat will be extracted from part of the effluent (approximately 550 m^3/h). This part of the effluent will therefore be cooled. This cooling will lead to a more natural temperature progression of the Geleenbeek and the Caumerbeek rivers, involved in effluent water discharge. This is beneficial for the ecology. However, the cooling of the effluent does cause temperature fluctuations, both in daily patterns and in the shorter term (approx. 15 minutes). The daily fluctuations are within the allowable margin. The short-term fluctuations are larger, but are expected to average out. Temperature measurements will soon reveal how and to what extent these fluctuations average out. Optional mitigation measures are in focus.

A location has already been reserved for the installation of Mijnwater on the WBL grounds. The most favorable routes for the pipeline route are currently being examined.

Conditions

Mijnwater is currently assessing which permits are required. A cold discharge permit is not required. A report has been drawn up for the environmental permit with the necessary components. In addition, the lawyers are currently examining whether a procurement law procedure is required or whether it can be deviated from.

An electric grid connection from the company Enexis is a requirement for the realization. However, due to grid congestion, new connections are usually rejected. Enexis is currently considering solutions for grid congestion. This means there is a possibility that a connection will still be granted, because we can demonstrate that the aquathermal installation leads to lower cumulative consumption than if individual solutions are chosen everywhere. This possibility is being further investigated.

WBL and WL make the heat available free of charge when it is clear that the heating network leads to social added value (including no higher costs for the residents of the center of Hoensbroek). One exception would be if it is legally necessary to charge money for the heat.

Mijnwater investigates whether there is a feasible business case based on the expected costs and benefits. A comparison is made with typical Mijnwater sources (boreholes).

Installation design

The design assumes an aquathermal installation with a capacity of 4 MW. This corresponds to an effluent flow rate of 550 m^3/h, and a temperature difference of slightly more than 5 °C from the effluent. In combination with a heat buffer, this can supply a peak demand of about 5 MW in Hoensbroek.

The installation consists of:

- Pumps and filters.
- 2 heat exchangers (probably plate exchangers) that extract heat from the effluent.
- 5 heat pumps that further increase the temperature to 65 °C.
- A heat buffer of approximately 1000 m^3 (preferably underground), which serves to absorb peak demand in Hoensbroek and to absorb downtime from the WWTP.

The heat (65 °C) is supplied to the neighborhood from the buffer. Any surplus is cooled to 35 ° C and delivered to the Mijnwater network.

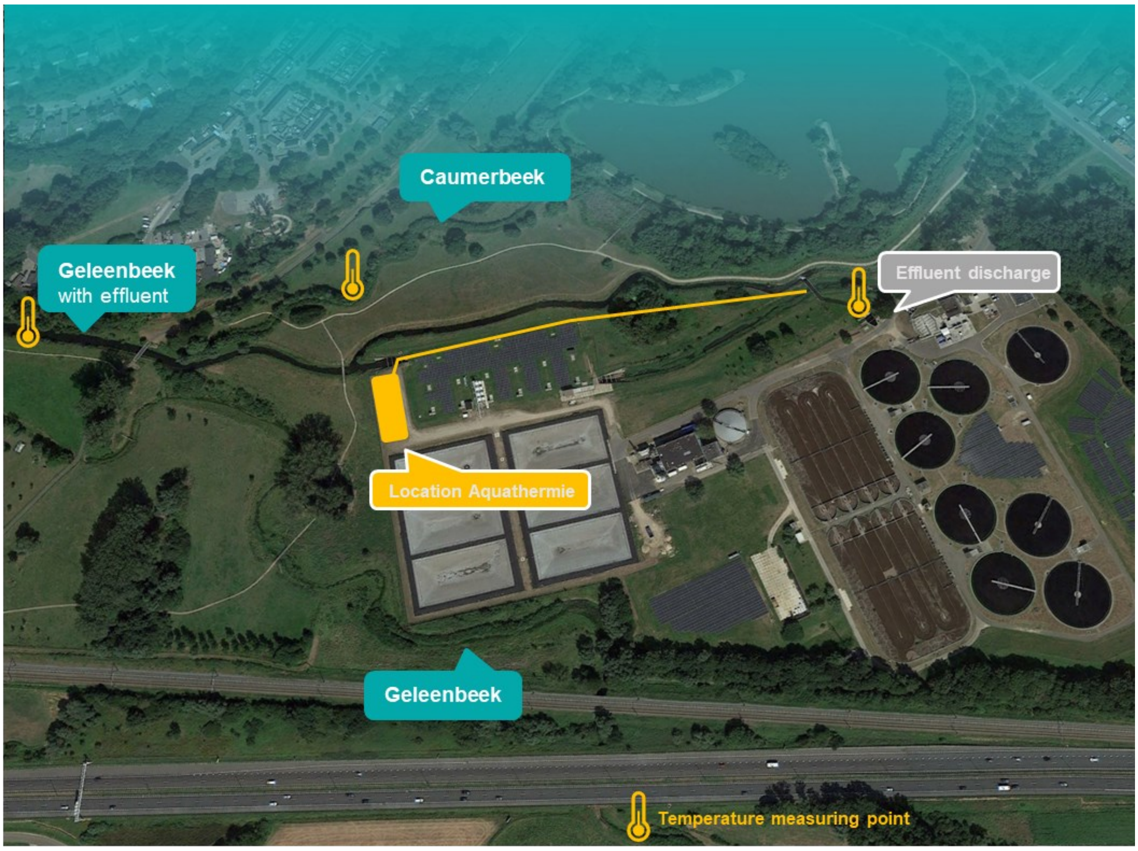

Figure 11. Satellite image of the Hoensbroek wastewater treatment plant.

4.5 Bridging solution for Brunssum

Due to a lack of balance facilities, the energy balance is currently deteriorating daily and measures must be taken in the short term. Taking into account the results of the studies and limitations already carried out, a bridging solution is necessary for the period up to and including the realization of a sustainable, structural solution. A bridging solution based on high-efficiency natural gas boilers can be realized relatively quickly and with very limited inconvenience in the area.

Compared to the criteria from Section 4.3, this solution direction is assessed as follows:

Table 7. Assessment of the bridging gas-based solution.

No.	Solution direction	Technical effectiveness	Business reliability	Technical feasibility	Impact on environment	Spatial Integration	Cost	Remark
X.	Central heating system with natural gas boilers	++	++	++	--	+	+	To bridge the period of 2-3 years until realization of a structural solution

For heat generation with natural gas boilers, a cascade arrangement of gas wall boilers (4 × 150 kW) and associated facilities is being considered, which is placed as a whole in a closed container of 3 × 6 m.

This setup consists of:

- Hydraulic and control facilities
- Buffer tank
- Condensation water drain
- Flue gas discharge
- Natural gas supply

The container containing the central heating system and additional facilities will be placed at the rear of the church on Pasteurstraat (see image 2). The church board has already agreed to cooperate. The container is surrounded by fencing and hidden from view with greenery. The existing supply and return heat pipes that run to the power plant are extended underground from the previous winter location to the container. In order to connect the container to the gas network, a new gas connection will be installed in the name of Mijnwater.

Figure 12. Site map with the temporary balancing facility.